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DEVELOPMENT OF A WEB-BASED PERISCOPE SIMULATOR FOR SUBMARINE OFFICER TRAINING

by

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September 2014

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LIST OF ACRONYMS AND ABBREVIATIONS

2D	two-dimensional
3D	three-dimensional
AO	Approach Officer
ARL	All Round Look
ASW	anti-submarine warfare
AT	Attack Trainer
BNSF	Brazilian Navy Submarines Force
BNSS	Brazilian Navy Submarine School
CBT	computer-based training
CCI	Critical Cue Inventory
CO	Commanding Officer
CSS	Cascading Style Sheets
GDC	Go Deep Range
GIMP	GNU Image Manipulation Program
GNU GPL	GNU General Public License
GODEX	Go-Deep Range Exercise
GPU	Graphics Processing Unit
GUI	Graphical User Interface
HTA	Hierarchical Task Analysis
HTML	Hypertext Markup Language
HVU	Higher Value Unit
IRB	Institutional Review Board
ITS	Intelligent Tutoring System
JSON	JavaScript Object Notation
KSA	knowledge, skills and abilities
MOP	measures of performance
NDM	Naturalistic Decision-Making
NPS	Naval Postgraduate School
OPORD	Operation Order
PD	periscope depth

PTT	part-task training
RMC	Rapid Mental Calculations
RPD	Recognition-Primed Decision
SD	safe depth
SMCC	Submarine Command Course
SO	Submarine Officer
SPA	Submarine Patrol Area
STP	Section Tracking Party
SW	submarine warfare
TADMUS	Tactical Decision-Making Under Stress
TMA	Target Motion Analysis
VRBS	virtual-reality-based Simulation
WBLE	web-based learning environment
WBS	web-based simulation
WEBS	Web-based Periscope Simulator
WSC	Winter Simulation Conference

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Usque ad sub aquam nauta sum!

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I. INTRODUCTION

A. RESEARCH PROBLEM AND MOTIVATION

The training of a submarine officer (SO) is a long, costly, and continuous process. Due to the complexity and danger involved in submarine operations, there is a set of basic knowledge, skills, and abilities (KSA) that must be developed by the officers to a minimum acceptable standard before they can be assigned to any role in the operational environment. Most of the topics that need to be learned by a trainee involve a proper utilization of the equipment and resources of the submarine. This fact would intuitively elect the submarine itself as the best learning tool. Indeed, in most navies, a considerable part of the training is performed aboard an actual submarine. However, there are some drawbacks that make it very difficult or even unfeasible to conduct courses relying on the use of actual equipment. Here are several factors that need to be considered before deciding on where and how to conduct that training:

- *Space*: The space aboard a submarine is scarce, and generally it accommodates only the room necessary for the crew to live and work amid equipment, especially in conventional submarines. Generally, each individual, who is predominantly the trainee in a deployment condition, represents one fewer bunk, decreasing the comfort of the crew. Very often it is just not feasible to have an entire cohort aboard, forcing more than one submarine to be deployed as learning tool for the phases of practice at sea. Even if the training can be conducted with the submarine ashore, the lack of space can represent an inconvenience for both the trainees and the crew.

- *Stress of the equipment*: The SO trainees must be prepared for the harshest possible situations; however, although the submarine equipment is made to eventually support extreme conditions of operation, using the same equipment repeatedly in those conditions for training purposes could reduce the life cycle of, cause costly damage to, and reduce the reliability of the equipment.

- *Costs*: The costs involved in training conducted aboard will not be limited to those related to the equipment maintenance and eventual repair. Since the training requires the submarine to be at sea, considering the case in which the submarine is assigned only for training, the cost can grow sharply. That cost will involve the costs to maintain the whole crew, fuel, etc. These operational costs are multiplied to each unit at sea, and they

grow even larger when the exercise requires the presence of surface ships, aircrafts, and other submarine units, as is the case for periscope tactics training.

- *Danger*: Underwater operations always represent high risks. Although the trainees generally are "shadowed" by experienced instructors, their instruction will often require the submarine to be put in dangerous situations where any flaw can be hard to control and reverse.

These drawbacks are considerably minimized if not completely removed by using simulators to teach the trainees before sending them to a final practical phase aboard the submarine. In Brazilian Navy Submarine School (BNSS), these simulators, called Attack Trainers (AT), are used to teach and train tactical maneuvers. They are built as full mock-ups of the submarine Command Room (henceforth referred to as "Control Room"), with the main sensors and equipment reproduced on a one-to-one scale. During the course of their career, Brazilian Navy SOs are submitted to at least three main courses in which they use those AT to build the KSA necessary to participate in a Submarine Command Course (SMCC): Basic Submarine Specialization Course, Preparation for the Duty of Periscope and Sound, and Submarine Operations for Officers. All these courses are developed in three different environments: classroom, AT, and aboard a submarine at the sea.

In the Basic Submarine Specialization Course, the students have their first contact with the subject of submarine safety and submarine operations, but the focus is mostly in theory. The newly graduated SO is not qualified for service in the Control Room as the Officer of the Deck (OOD). Although they have this first contact with theory, SOs do not practice in the tactical procedures, and have contact with the AT only as observers. The practical phase aboard is focused on the operation of equipment in preparation for the qualifying test.

In the next course, the Preparation for the Duty of Periscope and Sound, SOs are prepared to be qualified as OODs. This is generally the first opportunity in which they will use the AT. In this course the students need to apply the knowledge they obtained in the previous course. At the end of the course the students have a phase at sea, but with the

submarine operating alone; the focus is on the maintenance of safety, not in submarine warfare (SW) actions.

The third course, Submarine Operations for Officers, aims to expand the KSA acquired during the second course, focusing on tactical operations in SW. For the sea phase the trainees are required to plan, design, and execute SW operations in conditions similar to wartime scenarios. Besides the participation of a submarine, anti-submarine warfare (ASW) ships and aircrafts are mobilized for the sea phase in this course.

After those three courses, generally at the rank equivalent to Lieutenant-Commander (O4) or Commander (O5), SOs are enrolled in an SMCC. Most officers do the SMCC at BNSS, and some are sent to complete this course in other allied navies. Different from the previous courses, the SMCC does not have the focus on teaching new topics. The classroom phase is treated as a refresher for the entire content learned during the whole career.

This series of courses and education is spread over nearly fifteen years of an SO's career. Each course is a pre-requisite to the next one, but they can be separated by a time frame of several years. In the intervals between courses, each officer is responsible for keeping up the KSA previously acquired. Those assigned to the unit next to BNSS can ask for extra training at the AT; those training opportunities will be subject to the tight schedule of regular courses and maintenance. The officers serving in units far from the BNSS will have to find another way to prepare, but never with the help of a similar three-dimensional (3D) simulation.

Most of the KSA needed to match the exigency of the practical phases in the courses require lengthy practice, generally more than the timeframe allotted for the course itself. Despite the advantages brought by the use of simulators, they are not always available for those in need of training, for reasons such as schedule or geographic limitation. Even when simulators are available for extra training, extending the hours of their use could mean an increase of the costs of operation. A web-based learning environment (WBLE) would help minimize those drawbacks by offering an always-available tool for training, which users could adapt to their own schedule.

The criteria considered to appoint Commanding Officers (COs) of ships are similar in most navies. However, unlike on the surface ships, to be the CO of a submarine, an SO has to satisfy the common criteria and he also has to pass through the last test to compete for a command post: it is necessary to be approved in the SMCC. This last step involves a course that takes about three to four months, with small cohorts of up to six candidates. The exact format may vary from one navy to another, but it is very often a course with a high rate of failure. Due to those high rates of failure, the SMCC is commonly known as "The Perisher." There is only one chance for the future submarine Commanding Officers to perform this course, thus it is the ultimate test in the officer's career as a submariner. Failing SMCC means that the officer will never serve aboard the submarine.

All those characteristics can turn the SMCC into a daunting prospect for a long time; all prospective COs know they must be prepared when the time comes, for they will have only one chance. Although the theoretical knowledge and tactical skills are necessary to perform well in this course, the main objective of SMCC is not to teach those subjects, but to test if the candidates are able to keep acting as expected under a warlike situation, when they are pressed by time and the threats are presented to them. The tools to succeed in SMCC are built during the officer's career, whether with other courses or with the daily hands-on practice while on duty at the sea. The courses generally have phases of traditional classroom lectures, simulator practice, and final tests at the sea. The simulator is where SOs have the first opportunity to connect the knowledge and skills from the various sources. Some set of KSA necessary to begin training at the simulator cannot be developed during class time—they rely on massive amounts of information that needs to be acquired through a self-study. While the theory is taught in the classroom, each student still must find additional time to memorize the techniques and practice the rapid mental calculations (RMC) that they will be required to perform in seconds at the simulator training session. Once the students arrive at the simulator, they are expected to have practiced those KSA to a minimum acceptable level of proficiency; otherwise, it will be very difficult, sometimes impossible, to execute the simulator missions.

A shared understanding among those who have participated in such courses is that the trainee who masters the basic skills is not guaranteed to perform well, but the one who fails to master them, generally has a very bad overall performance, or may even fail the courses. The causes for bad preparation vary. Some trainees arrive without proper preparation because their current assignment did not provide them with enough spare time to practice. Others begin the courses unprepared because they did not have the right guidance, or the method that they had created to practice was not efficient, even though they worked very hard. Perhaps an even worse case is the students who do not fail the course, but who learned concepts by heart without really understanding them. After some time, the long list of memorized rules, if those did not include critical thinking and deep analysis, will be more difficult to recall, and the officer will gradually return to lower levels of readiness. Being that the objective of this kind of training is to improve the efficiency of the manpower, such deterioration of level of readiness only guarantees that this objective will not be achieved.

Following the evolution and widespread use of personal computers and the Internet, the use of distance learning WBLE is expanding nowadays. They arose as good solutions for professionals with a tight work schedule who are unable to invest time in more traditional forms of education. Driven by these facts, this thesis suggests the use of web-based simulation as a tool to be offered to SOs, to fill this gap between classroom lectures and simulator, taking advantage of the possibility to deliver 3D simulations using the web browsers and web technology. The objective is to create an effective and efficient WBLE that will be used by the SOs to guide and optimize their preparation time. The WBLE will illustrate very similar conditions and scenarios the students will be exposed to in the simulator when they take the training. The benefit of this approach is to allow trainees to form a solid basis before they begin the courses. The expectation is that students, once they have practiced different procedures and scenarios in WBLE, will be able to take the best of their simulator training session and focus their efforts on the development of more advanced skills, such as situational awareness and decision making. The web-based simulation could also help those SOs serving abroad, or the SOs who spend long periods of time outside the submarine; both groups need to remind themselves

of the concepts and recall their skills in preparation for the return to the submarine or for enrollment in an SMCC.

B. RESEARCH QUESTIONS

The issues exposed in the previous sections led to the following research questions:

1. What are the advantages of using a web-based 3D simulation?
2. What are the main knowledge, skills, and abilities (KSA) necessary for the performance of the Approach Officer (AO) and his role in a submarine, which can be either developed or improved with the help of a tactical periscope simulator?
3. Which of those KSA could be improved with the help of a WBLE, without the direct help of an instructor and outside the classroom environment?
4. Do WebGL compatible web-browsers have the resources to fully support a web-based 3D simulation?
5. What are the usability issues of a web-based 3D simulation (efficiency, effectiveness, and user satisfaction with the user interface)?

C. SCOPE

The thesis focuses on the training of periscope techniques using simulators; a goal is to identify the opportunities for delivering training using web-based periscope simulation. This type of training would represent a bridge between classroom teaching and training in the full-scale periscope simulators.

A prototype of a Web-based Periscope Simulation developed using open-source web-based technology is used to conduct a usability study and identify possible issues of this type of technology and training modality.

D. TECHNICAL APPROACH

To meet the proposed objectives, the following four-step approach has been adopted for this thesis work: literature review, task analysis, prototype development, and usability study.

In the first phase, a literature review will be conducted about the use of 3D simulations to teach SO and about the characteristics of web-based instruction. The objective is to gather knowledge available in literature about the benefits, issues, and limitations involved in the combination of 3D simulations, WBLE, and training, regarding the formation of SOs.

To expand and particularize the understanding of the task of the operator, a task analysis is conducted about the tasks and training sessions performed at the periscope simulator in BNSS. The main objective of the task analysis is to list the KSA needed for an SO to perform correctly at the periscope. In addition, task analysis is used to establish performance metrics and identify tasks suitable to be implemented and trained on in the WBLE. Most of the references needed to perform a thorough task analysis of the majority of the missions performed at the periscope are classified. In this thesis, only one mission has its task analysis reproduced, providing the level of detail that can be found in ostensive publications.

Based on the task analysis, the requirements for the WBLE prototype are defined. Observing the requirements defined in the previous phase, a prototype is developed to implement those tasks in a web-based environment. The main technology used for development is WebGL, an open-source JavaScript API, that allows rendering 3D graphics within Internet browsers, without the need for any plug-in or installation in the user's computer.

In the last phase, the usability of the prototype is tested; test subjects were able to access a version of the prototype published on a website and complete a survey about their experience. The usability study aims to assess the usability of the human-computer interface built, identifying the points of strength and weaknesses, collect insight about the

feasibility of the technology for wide distribution, and gather the subjective opinion of the average Internet user about this modality of training.

E. THESIS CONTRIBUTIONS

The main contribution of this thesis is a series of understandings related to a possible application of the web-based 3D simulations in military training. The data about the viability and utility of a 3D web-based simulation for training was gathered and analyzed for more detailed insights. The results of the survey provided insights about the user's online habits and their acceptance of web-based training.

The study also collected and organized a set of understandings about the cognitive processes and the mindset of AOs during SW operations, particularly for the operation of diesel-electric submarines on periscope depth (PD)—a depth in which it is possible for a submerged submarine to raise the periscope mast over the sea surface.

The WebGL software standard used to develop the prototype training simulation, allows 3D rendering in the web-browser without the need for any software installation. However, the WebGL standard is currently not completely supported on all hardware and software platforms available on the market. The data and knowledge we collected about this standard and the results of our usability study allowed us to highlight the advantages and limitations of this technology, and to give the insights about the feasibility of a wide distribution of simulations that would use this technology.

F. THESIS STRUCTURE

This thesis is organized as follows:

Chapter I states the problem addressed, presents the motivation for the study, names the objectives of this thesis, and describes the methodology adopted to approach the problem and reach the objectives stated.

Chapter II provides the background information necessary to better understand the problem stated. The peculiarities and difficulties of SW within the scope of this thesis are explained in more detail, discussing the cognitive aspects and mental models for decision making inside the SW context.

Chapter III consists of a literature review divided in two parts. The first part presents the results of a review about the use of 3D simulations for submarine training, discussing the suitability and efficiency of those simulations as training tools. In the second part, an analysis is made about the characteristics of WBLE regarding the advantages, disadvantages, and peculiar pedagogical aspects of it.

Chapter IV describes the missions performed at BNSS AT, and presents the task analysis conducted in one main mission to identify the tasks that would be suitable for implementation in a WBLE. The learning objectives and measures of performance (MOP) are then identified for these tasks to finally list the requirements for designing the WBLE.

Chapter V outlines how the Web-based Periscope Simulator (WEBS) was designed and prototyped.

Chapter VI discusses the design, execution, and results of a usability study to test the WEBS prototype.

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II. BACKGROUND

The Web-Based Periscope Simulation (WEBS) focuses on the training of SOs for techniques to be used at PD; this chapter briefly introduces some concepts behind these techniques. A basic comprehension of some periscope techniques will be indispensable to analyze the missions executed at PD, and this chapter will also help readers understand the cognitive processes related to the scope of this thesis.

A. THE PERISCOPE TECHNIQUES

The techniques used for operation of the periscope were developed as a trade-off: the goal was to maximize information acquisition with the least possible submarine indiscretion. Some of these techniques began to be developed as early as World War I, when most submarine attacks were performed within the visual range, in a very close approach to surface ships. Modern submarine weapons and sensors have ranges beyond the horizon, making it very unlikely that a submarine will get as close to surface vessels (contacts) as was typically the case until World War II. However, the skills necessary to maneuver a submarine safely in the presence of several surface contacts, using only stopwatches and mental agility, remain valuable for the training of a submarine CO (White, 1993). Some periscope techniques are still applicable nowadays, either because they are still useful in the modern SW scenario, or because they help to instill in the SO the mentality of safety and self-confidence. Furthermore, they are also valuable to teach mental models. Even though nuclear submarines have a different employment doctrine, the experience with courses like the SMCC, where those techniques are covered, represent an opportunity to observe the inside of diesel-electric submarines and understand the mindset of a conventional submarine CO (Steketee, 2004).

The periscope is the only sensor capable of providing a complete set of data about the tactical situation around the submarine in a matter of a few seconds. However, as an optical sensor, it has all limitations naturally imposed by the light spectrum. The range of a periscope is geometrically limited at sea due to the Earth's curvature, and it is susceptible to atmospheric conditions influencing visibility. Besides, at PD the submarine

is made more vulnerable to counter-detection by ASW surface and air units. However, despite those disadvantages, periscopes continue to be of paramount importance to ensure the safety to the dived submarine, and to collect or confirm tactical information.

Due to the inherent margin of errors and uncertainty of other passive sensors, the periscope is the only sensor able to resolve with conviction the potentially questionable data sets acquired by other sensors. The operator is able to collect reliable information about the surrounding tactical situation in a matter of seconds, calculate the geographical position of the submarine and reveal the identity of targets. The information collected by a periscope usually can be used right away, because they are useful without the need of further processing (other than human interpretation).

1. Safe Depth

The concept of *safe depth* (SD) is a theoretical base that drives most of the other safety calculations for a submarine at PD. It is the depth at which the submarine can transit within a safe distance from the keel to the sea bottom while still allowing ships to safely pass over the fin (see Figure 1). The Standardization Agency for North Atlantic Treaty Organization (NATO) defines SD in a following way:

> A submarine is said to be at Safe Depth when its keel depth is such as to provide the required separation between the top of the fixed structure of the submarine and the lowest point of any ship, other submarine assigned to a higher layer, towed ASW device and/or helicopter sonar systems allowed in the orders for the exercise. When more than one towed device is being used in the exercise, Safe Depth applies to the deepest device being employed. (North Atlantic Treaty Organization [NATO], 2002)

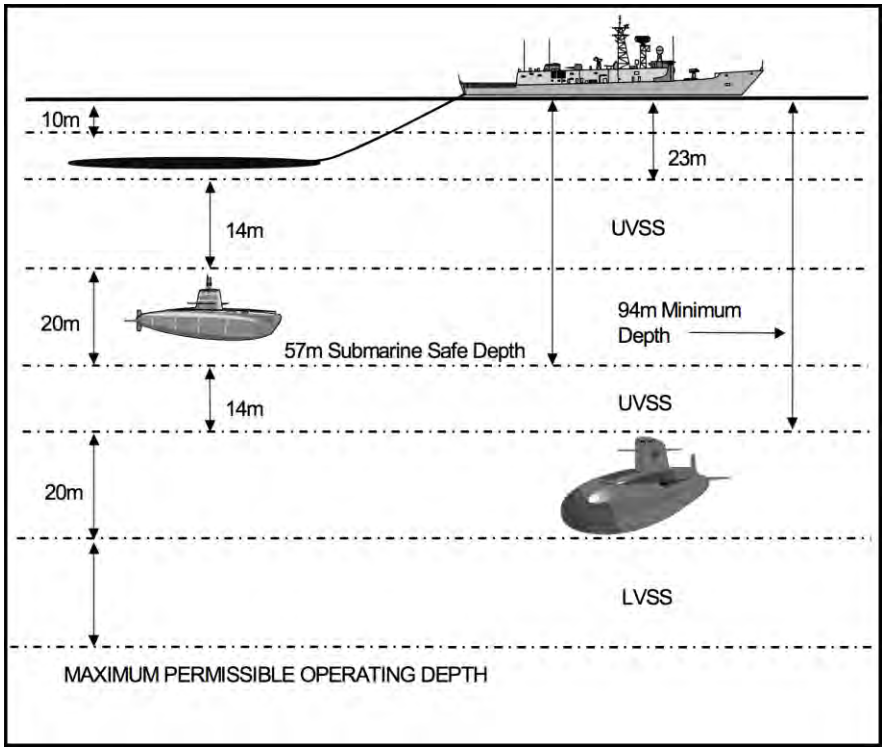

Figure 1. Safe depth calculations (from North Atlantic Treaty Organization, 2002, pp. 2–13).

Thus, the SD will depend on the types of ships expected to be navigating on a given Submarine Patrol Area (SPA) to which the submarine was assigned or in part of a transit route.

2. "Go Deep Circle"

For a given SD calculated, each submarine class will need a certain amount of time to go deep according to its rate of descent (movement from PD to SD). The *Go Deep Circle* (GDC) is a locus of the distances measured from the submarine. It represents the distance that can be covered by a surface ship while the submarine is diving from PD to SD. In Figure 2 there is an example of a GDC calculation.

In periscope drills conducted for the safety phase of courses, the trainees are required to do RMC to figure out the GDC of new contacts. Aiming to exemplify the cognitive load imposed on the mind of the AO by RMC, the calculations for the situation in Figure 2 will be detailed: the submarine in this example takes a time T_{SD} equal to 60

seconds to go deep, travels with a speed of seven knots, and is observing the Ship A, which develops a maximum speed of 29 knots. GDC calculation always considers the worst-case situation to build a buffer of safety. For the given example, the submarine and the Ship A are on the same line, moving toward each other. The relative velocity of approach $\overline{V_R}$ is the vector sum of the Ship A and submarine velocities.

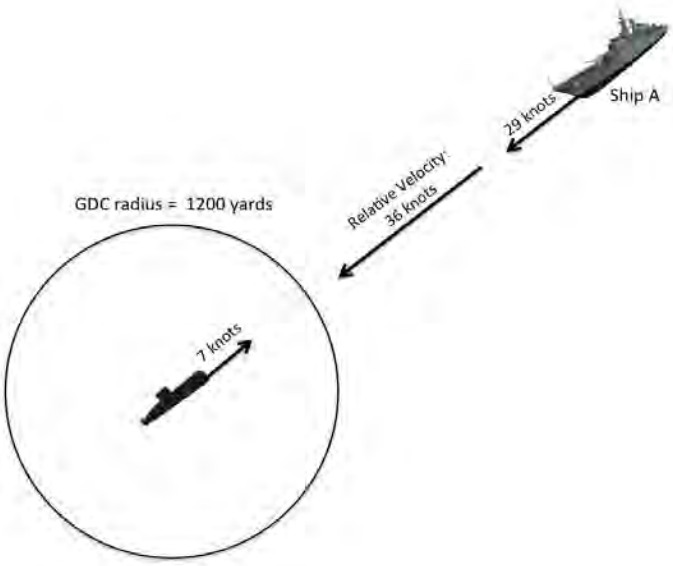

Figure 2. Calculation of the Go Deep Circle.

$$GDC[yards] = \frac{|\overline{V_R}[knots]|100}{180} T_{SD}[seconds] \quad (1)$$

$$GDC = \frac{(7+29)100}{180} 60 = 1200 yards \quad (2)$$

With a relative velocity of 36 knots, the submarine and the ship will approach 1,200 yards in 60 seconds. This is the calculated GDC radius for this class of ship. If any ship with the same characteristics of Ship A reaches the GDC, the submarine will be forced to go deep.

While this calculation renders more safety, it extends the worst-case to the whole circle, giving less flexibility to the submarine. There are several practical ways to

decrease the GDC by sectors, aiming to confer more flexibility to the submarine, while still keeping it safe. The mathematical fundament to reduce the GDC by sectors is exemplified in Figure 3. However, the exact way it is applied can be different in each navy, and is generally based on classified publications.

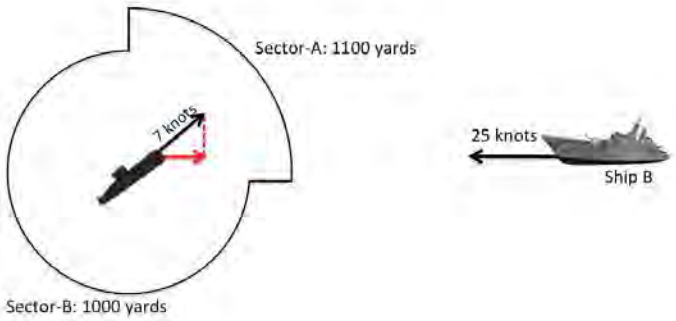

Figure 3. GDC reduction by sectors.

In this example, in order to create a reduced GDC sector, the submarine velocity vector was projected 45 degrees to each side, and this value was extended to the rear sector, as shown in Equation (4) Ship B has a maximum speed of 25 knots.

$$GDC_{ahead} = \frac{(7+25)100}{180}60 \simeq 1100\,yards \tag{3}$$

$$GDC_{astern} = \frac{\left[7\cos(45^{o})+25\right]100}{180}60 \simeq 1000\,yards \tag{4}$$

3. "All Round Look" Interval

The *All Round Look* (ARL) is a basic periscope technique. It consists of turning the periscope all the way around to quickly obtain situation awareness about the environment above the sea surface. The periscope mast is raised to execute the technique

and lowered just after completing it. The whole movement must be executed as fast as possible to minimize the exposure of the periscope mast, but slow enough to make sure that all visible contacts between the submarine and the horizon will be detected.

To calculate the acceptable time interval between two ARL's, the worst-case is considered: a new contact appears just after the periscope looks toward its direction. This contact is not detected and approaches the submarine with its maximum speed on the closest approach distance. The time it takes for this contact to reach the GDC perimeter must be greater than the maximum interval between two consecutive ARLs, in order to ensure that it will be seen before reaching the GDC.

If more than one type of contact is expected for a given SPA, the smallest interval will be assumed (shown in Table 1). For the simplicity the example one can consider the submarine traveling at seven knots and having the same SD for the three different classes of ships, taking exactly one minute to go deep. Therefore, for the example in Table 1, the ARL interval to be considered is three minutes and ten seconds.

Table 1. Example of ARL Interval calculation.

Type of Contact	**Sighting Distance (yards)**	**Maximum Speed (knots)**	**Approximation Rate (yards/minute)**	**GDC Radius (yards)**	**Time to Reach GDC**
Ship class "A"	5000	29 knots	1200	1200	3'10"
Ship class "B"	8000	23	1000	1000	7'
Ship class "C"	2500	8 knots	500	500	4'

4. "Look" Intervals

After a new contact is detected, periscope observations can obtain further data, such as the classification, distance, speed, and course of that contact. Knowing the exact distance of the contact and a point in time, it is possible to calculate how much time this contact would take to reach the GDC and jeopardize the submarine using the same reasoning as ARL intervals. This calculated amount of time is known as *look interval* (LI). For each new contact there will be an LI to be controlled, and at every new

observation this LI will be updated accordingly. One of the abilities required from trainees in some submarine courses is to be able to mentally calculate and control several LIs and the ARL interval at the same time, using separate stopwatches (White, 1993).

B. COGNITIVE ASPECTS IN PERISCOPE-DEPTH OPERATIONS

This section analyzes the main aspects of AO cognition during the approach phase; different cognitive theories will be leveraged to provide this understanding. A full comprehension of the cognitive processes that occur while the AO is addressing an operational situation is needed to understand the benefits that WBLE adds to an individual's training.

An act of planning the approach of the submarine towards an objective represents a strenuous cognitive workload for the AO. This is especially the case when the approach has to be made on PD and in shallow waters. The AO is pressed by time and a sense of jeopardy. The decisions must be made relying on information with a high level of uncertainty aggregated. The situation can change dynamically, yet the decisions must be taken upfront, betting on predictions of future situations. The objective of this section is to analyze the existing theories about the cognitive processes of an AO in this environment and its specific conditions.

1. Naturalistic Decision Making

The characteristics of the situations in which the AO has to make decisions are: time constraints, high uncertainty, high risk, a complex and dynamically changing environment, ill-defined and competing goals and sub-goals. All of this makes the domain related to the *naturalistic decision-making* (NDM) theory (Kirschenbaum, 2001). In the classic decision-making model, it is assumed that the decision maker generates a list of courses of actions and then chooses the best solution in the list of possible solutions. While doing that, the decision maker is conducting a thorough analysis of all available information and considering all hypotheses under the cost-benefit criterion. This framework of decision making turns out to be unrealistic for emergent situations and harsh environments (Hutchins, 1996). On the other hand, NDM theory rests on the belief

that the decision maker passes through a more naturalistic process of perception, comprehension of the situation, and generation of appropriate responses (Klein, 2008).

Amid the NDM theories, perhaps the best known and best fit for the submarine problem, is the *recognition-primed decision* (RPD). The RPD theory relies on two key concepts: situation assessment and mental simulation (Klein, 1993). In RPD, the decision maker assesses the situation to identify a satisfactory course of action, and then evaluates the option through mental simulation, rather than making cost-benefit comparisons on all available options (Klein, 1993). In situation assessment, when presented with a new problem that needs to be solved, people use their previous experience with similar past situations, recognize patterns and match with the features of the current problem. They automatically recall and adapt information learned from the previous known situation to help solve the current problem. When they are faced with a new problem for which they have no similar experiences in the past, they will consciously use mental simulation to understand the problem and create viable solutions (Shattuck & Miller, 2006).

Analyzing the decision-making process of a submarine approaching, Kirschenbaum (2001) found that the AO "uses his expertise to recognize and instantiate appropriate schema. He uses this schema as the basis for action in an interactive feedback loop" (p. 203). This feedback loop is based on two mechanisms: (1) common information-gathering strategies and (2) shallow goal stack that allows the AO to rapidly adapt to changes on the situation (Kirschenbaum, 2001).

2. Situation Awareness

Situation Awareness (SA) in the scope of SW can be defined as the understanding that an AO has about the current tactical situation and the possible developments or consequences in a close future. In other words, in order to support the process of decision making, the AO builds a mental model in his or her mind. Endsley (1995) proposes the division of the SA process into three major hierarchical phases:

1. Perception of pertinent data in a time and space frame
2. Comprehension of the perceived data
3. Projection of a near future situation

In the context of PD operations, the first phase represents the collection of data relevant to the situation by the SO. These data are about the own submarine, the environment, and the other units detected. Table 2 lists some of the most common data collected by the AO in PD operations. As noted by Kirschenbaum (2001), most traditional models consider that all the necessary data will be available in this phase to support the individual in building his or her SA. However, in the domain of SW, each iteration of data collection is likely to render only a subset of the necessary data, forcing the AO to rely on estimations and suppositions to complete the necessary operation. Even the data successfully obtained can be misleading due to the large amount of noise added by environmental sources, a common occurrence for information from the sonar. Furthermore, most data about other units cannot be used in the raw form of collection. To become useful, some data need additional mental or computational processing. For example, to obtain the course of a surface ship using the periscope, the AO collects and inverts the ship's bearing, visually estimates its angle on the bow (AOB), and mentally calculates the course as the sum or subtraction of these two values, as shown in Figure 4.

Table 2. Example of relevant data perceived by the SO.

Data about the own submarine	**Environmental data**	**Data about other units**
- Heading - Course over ground - Propeller revolutions per minute - Speed over ground - Depth of the keel - Hull inclination (bubble)	- Visibility - State of the sea - Direction and height of the sun - Current	- Classification - Bearing - Distance - Course - Speed - Level of danger - Recent data history

The second phase consists of building a mental model of the current situation; the loose elements collected previously are put together and combined according to existing patterns learned by the AO. The pieces of information that have been obtained are

combined to gain a full meaning, converging to an interpretation of what is possibly happening. Unlike some other domains, a domain of SW is characterized by the existence of a high degree of uncertainty. Even the decisions to manoeuver the submarine may affect the accuracy of data, increasing or decreasing the level of uncertainty (McKenna & Little, 2000). The lack of data and the errors introduced by estimations and noise, force the AO to frequently build a mental model of the situation consisting of a best guess rather than a complete and clear comprehension of data. It is similar to the assembling of a jigsaw puzzle with missing pieces. In spite of the uncertainty, experienced AOs use their mental models to confirm or disregard the solutions from the computer and the data calculated by the Submarine Tracking Party (STP) (Kirschenbaum, Trafton, Schunn & Trickett, 2013).

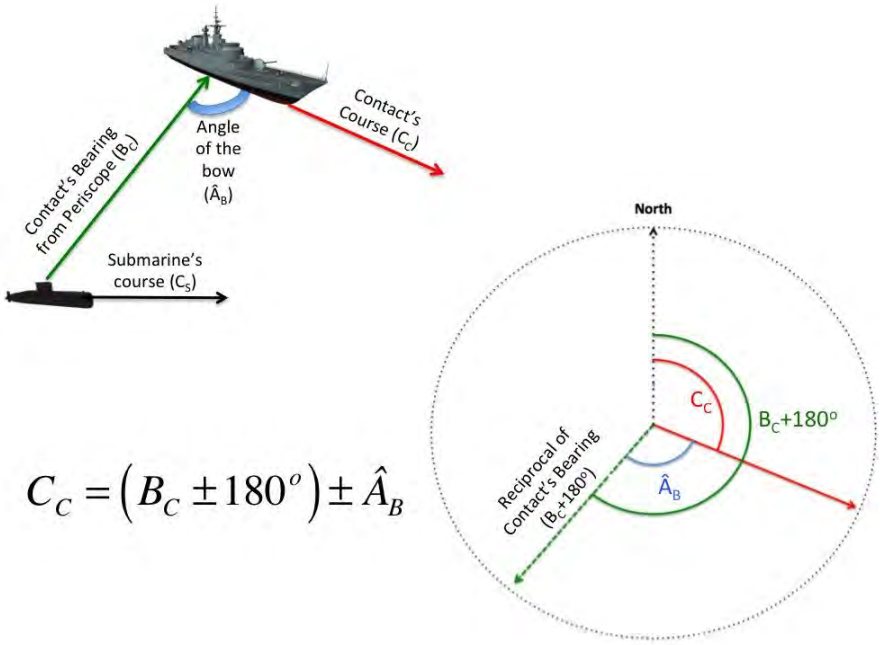

Figure 4. Example of mental calculation of a contact's course, based on visual estimation of the angle on the bow.

The AO derives the projection of the future status using his understanding of the current tactical situation. This is the highest level of SA to be achieved (Endsley, 1995, p. 37). The projection into the future situation is especially important for conventional diesel-electric submarines. Due to the speed disadvantage when compared to most surface vessels, diesel-electric submarines must make decisions and act in advance, betting on a prediction. This level of SA must be achieved in a timely manner if the goal is to make correct decisions and to position the submarine favorably for the upcoming action. Any delay or miscalculation can cause the mission to go irrecoverably wrong. Particularly complex in this domain is the fact that the situation is dynamically changing. Noise and dynamic changes in attitude are deliberately introduced by the surface units, as they try to deceive the submarine solutions (Ehret, Benjamin, Gray & Kirschenbaum, 1997).

The human perception is intertwined with the system sensing of the environment throughout the process of SA building; the AO uses information processed both by humans (the own AO and the SAP) and by machines. A good model for cognitive processes like this was proposed by Shattuck and Miller (2004), as illustrated in Figure 5. In this figure, we can see how the whole set of data from the environment arrives to the AO already sieved by the sensory capacity of the system (represented by oval 2), which limits detection, and by the selective displaying of detected information (oval 3), as some information may be misjudged or considered irrelevant by the system or by the human operator.

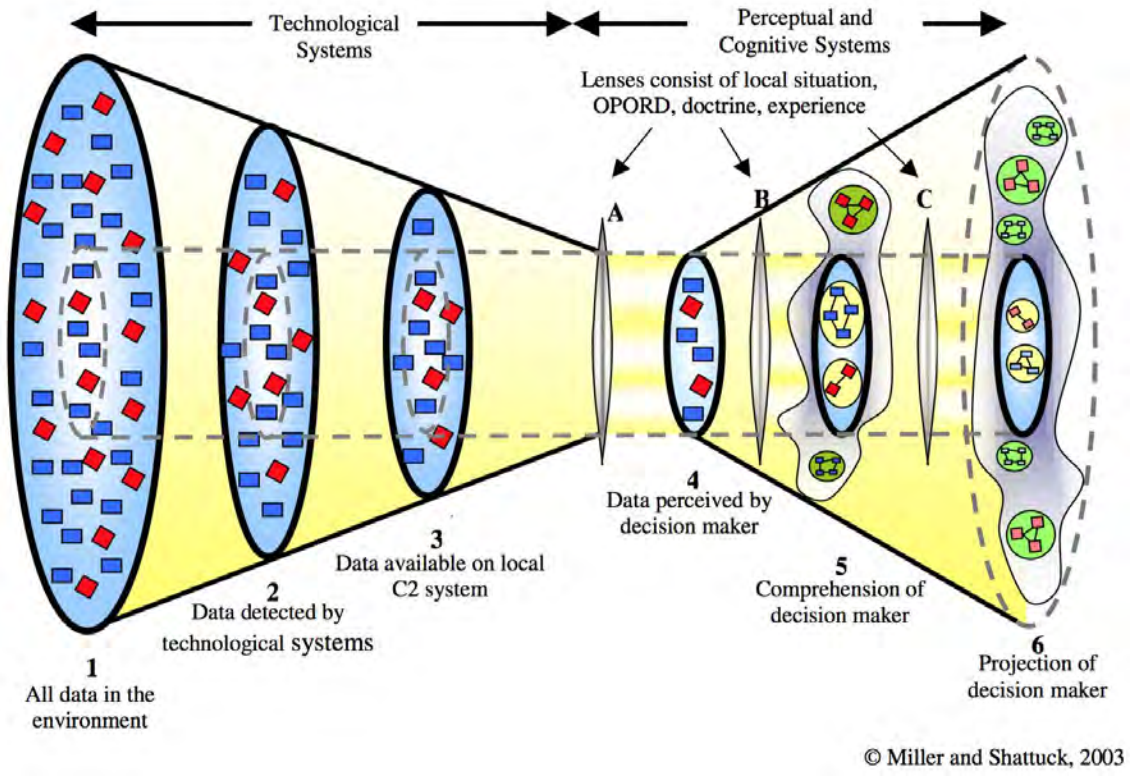

Figure 5. A Dynamic Model of Situated Cognition (from Shattuck & Miller, 2004, p. 660).

Once the information reaches the AO, it will be subjected to what the model names "lenses." Those lenses are, in this context, the local situation, Operational Order (OPORD), doctrine and experience. The local situation will lead the AO to pay more or less attention to a determined set of information; this set is judged to be more important or urgent to the current situation. The OPORD represents the superior orders, the mission assigned to the submarine, and the doctrine is a general set of guidelines within which the AO was taught to act. Finally, the experience recalls past activities that the AO may have practiced before that bear similarities to the current situation (Shattuck & Miller, 2004).

3. The Influence of Stress

Stress is a constant factor accompanying submarine operations, and it is essential to understand how stressful situations can influence the cognitive process. There are many sources of stress for the AO: the characteristics of the submarine with all the risks involved in operating under a massive body of water, the responsibility for making

decisions that may have harsh consequences, a constant uncertainty of information, a time pressure, a need to execute several parallel tasks, etc. The conditions faced by the AO match those listed for the *Tactical Decision-Making Under Stress* (TADMUS) project, conducted by the United States Navy (Cannon-Bowers, Salas & Grossman, 1992):

- Multiple information sources: The AO must manage the information that he or she collects from the periscope, the information available from the other sensors and the information generated by the STP.

- Incomplete, conflicting information: Different stations of the STP frequently diverge about the solutions found.

- Rapidly changing, evolving scenarios: The opposing forces purposely insert dynamic changes to their behavior, to difficult the action of the submarine.

- Requirement for team coordination: The AO is the conductor of the STP.

- Adverse physical conditions: An approach on PD can be very physically demanding, as the AO must successively raise and lower the periscope.

- Performance pressure: The AO is the capital decision maker, and the responsibility for the success or failure of the mission is on his shoulders.

- Time pressure: An AO is under time pressure during all the execution of an approach.

- High work/information load: Besides being responsible for the processing of a high load of information and decision-making, the AO still has to care about the safety of the submarine and the aspects concerning the management and leadership of the crew.

- Auditory overload/interference: Most of the information is received verbally by the AO.

- Threat of hostile engagement: Both for real operations and for exercises, where the surface units play figurative enemies.

One's concentration and selective attention can be severely compromised under high stress, impairing the individual's performance and significantly affecting the ability to perform decision making (Entin & Serfaty, 1990). Courses like the SMCC are designed to push the trainees up to the edge, forcing them to face their own limitations, and helping them to improve their decision-making ability under pressure (Forster, 1996).

One of the approaches for the training of decision making under stress is part-task training (PTT). PTT consists of decomposing a more complex task into components that can be separately trained (Wightman & Lintern, 1985). Kirlik, Fisk, Walker and Rothrock (1998) list some lessons learned from their research about the use of PTT to train dynamic decision making:

- To train high-level cognitive skills and decision-making, ensure that the individuals have mastered the perceptual and motor skills that they will need in order to interact with the environment.
- A good approach to train these basic perceptual and motor skills is PTT.
- The components of an overall complex task when identified and trained to the level of automaticity help to alleviate high-workload situations.
- The automation of components of a task turns its performance more reliable despite of the insertion of stress into the situation.
- PTT must be supplemented with the training of the full-task.

However, Klein (1996) draws attention to the fact that stressors can either disrupt or improve performance. He highlights that the natural adaptations to stress should not be suppressed, since these adaptations frequently focus the human effort on the selection of simpler and more robust decision strategies. Instead, training should focus on preparing decision makers to handle the pressure imposed by external factors, such as time constraints.

C. CHAPTER SUMMARY

This chapter presented the main background information to help understand the cognitive processes and mental models developed by AOs in PD operations. Some technical concepts were detailed to stress the mental calculations used in periscope techniques, and give a dimension of the cognitive load to which trainees are submitted during periscope drills. Next, the cognitive processes of PD operations were analyzed under the light of existing cognitive theories, explaining how it is suitable to NDM theories, the SA building process, and the influence of stress on cognition, highlighting the use of PTT as an approach to facilitate the execution of complex tasks in stressful environments.

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III. LITERATURE REVIEW

A. INTRODUCTION

The literature review performed in this chapter is divided into two parts: (1) an examination of established literature about the general aspects of simulations for training, giving emphasis to its application specifically for SO training, and (2) review of the characteristics, benefits, and caveats of the WBLE. The aim of this literature review is to answer the first research question: what are the advantages of using a web-based 3D simulation?

B. THE USE OF SIMULATIONS FOR SUBMARINE OFFICER TRAINING

The definition of a simulation, according to the United States Department of Defense is: "a method for implementing a model over time" (Department of Defense, 1994). Inside this definition, simulations can assume diverse formats and be used for several different objectives. Respecting the boundaries of the scope of this thesis, the literature review will be focused on computer-based 3D simulations used for training, especially when applying self-paced learning approaches, discussing their general characteristics, advantages, and disadvantages.

1. Simulations for Training

Among the computer-based simulations used for training, we are particularly interested in those that use virtual reality technology. Virtual reality, often called 'virtual environments,' is an interface paradigm using computers and human-computer interfaces to create the effect of an interactive 3D world (Bryson, 1996). Brooks (1994) cites four components of virtual reality:

- Real immersion – world is life size.
- Real time – viewpoint changes as eyes move.
- Real space – concrete or abstract 3D worlds
- Real interaction – it is possible to manipulate virtual objects

Virtual reality based simulations (VRBS) have been successfully used for training in several domains, such as aircraft pilot SA, space telepresence for astronauts, and the training of future submariners (Stone, 2002). Facilities with computer-based simulations working with full-scale replicas of equipment have been used for all sorts of complex skills training, from vehicle operation to infantry training. These simulations are especially useful for military applications (Salas & Cannon-Bowers, 2001).

As training tools, simulations are able to offer advantages when compared to traditional classroom teaching, since they can be built to put the trainee in situations and conditions very similar to those one would face in the real world (Chung, 2003). Evidence has been found that simulations are effective for teaching complex skills, and that, in training with simulations, there is effective transfer of skills (Salas & Cannon-Bowers, 2001), as in the work cited from Gopher, Well, and Bareket (1994), in which the skills were transferred from a computer game-based simulation to real flight. One of the reasons why simulations are found more valuable in contrast with other training delivery methods is that in simulations the trainee can experience the actual performance of a job and its immediate response (Kindley, 2002) while not being exposed to the real risks or costs of the real situation (Becker & Parker, 2009).

Some of the benefits of training simulations, as cited in literature, that can be directly applicable to the training of periscope tasks are:

- *Cost savings*: The costs to deploy a submarine involve high numbers, considering the maintenance of equipment, personnel, and the deployment of surface and air units to support exercises (Orlansky, Dahlman, Hammon, Metzko, Taylor, & Youngblut, 1994; Thompson, Carroll, & Deaton, 2009).

- *Replication of a large collection of standardized scenarios in a controlled situation*: Trainees can be presented with a large range of different scenarios of the real world beyond those presented in the curriculum. This is especially interesting to present the trainees with situations that would represent high risk for human lives or equipment if performed in real situations (Thompson et al., 2009).

- *Time savings*: Simulations can compress the time of lengthy operations, helping the trainee to make the link between the action and consequence. (Chung, 2003). For example, the transit of the submarine from one area of

the exercise to another can take a long and unfruitful time that can be compressed with the use of simulations (Chung, 2003).

- *Creation of a blame-free environment in which to make mistakes*: Mistakes made by the learner, when in a safe and blame-free environment, can be a powerful learning mechanism (Hills, 2003). In exercises performed at sea with the real equipment, the trainees tend to be more limited in their actions due to their fear of real mistakes and their consequences.

However, despite of all those advantages, it is important to keep in sight that simulations are nothing but a tool (Salas & Burke, 2002). The simple use of a simulation for training is not a guarantee of improved learning (Salas & Cannon-Bowers, 2001) (Salas & Cannon-Bowers, 2001). Moreover, the advances in fidelity and resolution do not necessarily carry the same improvement in training quality. In short, the simulations share the same design issues and risks of negative training as any other training tool (Salas, Bowers, & Rhodenizer, 1998).

2. Simulations Applied to Submarine Officer Training

These characteristics of simulations intuitively suggest the use of simulations for submarine training. Simulations have already been a part of submarine training for a long time; they have been combined with years of learning in the classroom and experiences at sea (Kirschenbaum, 1989). The application of VRBS in submarine training facilitates the building of complex mental models necessary for the effective use of periscope techniques before the trainees encounter large simulators with the mock-up instrumentation. In spite of possible technology limitations, such as visual fidelity and auditory realism, the benefits added by the use of simulations outweigh the negative aspects encountered in those systems (Vincenzi, Hays, & Seamon, 2003).

Indeed, computer-based simulations have been widely used for several submarine trainings, both at the individual and team levels (Jones, 2008). For the objectives of this thesis, particularly interesting are the applications of simulations designed for training using personal computers. Those simulations are generally cost effective and focused on PTT, rather than the training of a full and complex mission involving the convergence of various KSA. Some examples of these smaller simulations found in literature include:

- Submarine Ship Control Training Program: A cost-effective simulation implemented on personal computers for self-paced learning of the principles of submarine ship handling (Biegel, Brown, Mason, & Poland, 1998).

- Bottom Gun: A game-based application developed to train visual estimations of the AOB and the distance of surface contacts using a periscope simulation (Garris & Ahlers, 2001).

- Web-based Maritime Training Environment: The paper describes the development of a web-based simulation (WBS) modeled and developed to get around the high costs and low availability of full-scale maritime simulators (Cui, Yicheng, Xiuwen, & Yong, 2004).

- Submarine Onboard Training (SOBT): Among a list of simulations used for submarine crew's training cited, the work elaborates how a course originally designed for four weeks of classroom and laboratory training, was reduced to a one-week laboratory course. In that example a classroom portion of the training was replaced by a self-paced training onboard. The training was a part of the SOBT program (Jones, 2008).

- Adaptive Training System for Submarine Periscope Operations: The researchers evaluated the effectiveness of a periscope simulation in association with an adaptive training system used for training of basic periscope skills (Landsberg, Mercado, Van Buskirk, Lineberry, & Steinhauser, 2012).

A remarkable feature of those simulations was the application of self-paced learning. In a field experiment with novice computer users, Simon and Werner (1996) found that self-paced learning rendered higher cognitive learning and skill demonstration than the lecturing approach.

C. USES OF WEB-BASED SIMULATION AND WEB-BASED LEARNING ENVIRONMENTS

This section presents information from the literature about the use of WBS for training. The evolution of WBS is briefly discussed, citing the evolution of the tools that currently enable its implementation on web browsers. Advantages and disadvantages of WBLE are discussed, stressing the main human factors to be considered in WBLE. Since the aspects related specifically to simulations were discussed in the previous section, this section will be focused on the aspects of WBLE. Many considerations are not specific to

WBS, even though, since WBS is also a representative of the field of WBLE, the objective was to highlight the characteristics of WBLE that are relevant for WBS.

1. Definitions

The idea of WBLE involves the creation of a meaningful learning environment with an instructional program that takes advantage of the attributes and resources of the Internet (Ritchie & Hoffman, 1997).

A WBS is any representation of the field of simulation delivered to the user through the Internet (Huang & Madey, 2005). Thus, by this definition, WBS inherits a large number of applications for the field of simulations. There are WBS for analysis, testing, etc., but the type of WBS interesting for this thesis are only those used for training. As a training tool that is delivered to the users through the World Wide Web, WBS can also be defined as WBLE, bearing at the same time the features of VRBS and WBLE. The hatched area in the Venn diagram of Figure 6 illustrates this superposition.

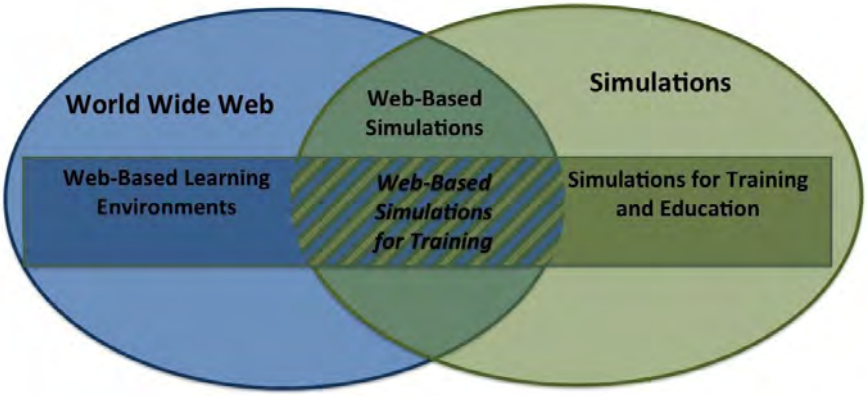

Figure 6. Venn diagram contextualizing WBS for training.

2. The Evolution of Web-Based technology

Internet technologies have been in constant evolution, since the early 1990s. The efforts of software developers are directed towards adapting all kinds of traditional applications to make them available on the Internet (Fishwick, 1996). Simulations are not an exception. The subject of WBS was addressed at a session in the Winter Simulation Conference (WSC) in 1996 (Buss & Stork, 1996; Fishwick, 1996; Nair, Miller, & Zhang, 1996), and the first dedicated forum about the issues related to WBS was held at the WSC of 1998 in San Diego, California. In the year of 2000, WBS became a specific area of the WSC.

Early attempts at implementing simulations on the Internet often relied on Java applets (Page, Buss, Fishwick, Healy, Nance, & Paul, 2000; Harasim, Calvert, & Groeneboer, 1997; Kuljis & Paul, 2000) and VRML (Virtual Reality Modeling Language). In 2011, the WebGL standard was released, allowing the rendering of 3D objects on the HTML5 canvas element of a browser to enable accelerated processing of images in the graphics processing unit (GPU). This technology was not developed only to support the simulations or virtual environments on the Internet, but in this thesis, the adequacy of WebGL for this kind of application will be assessed.

3. WBLE Advantages

The advantages offered by any WBLE will depend on the intended settings and on the nature of the training system designed (Cook, 2007). Some advantages that are specific to WBLE due to its features are:

1. *Accessibility*: Virtually any place in which there is a device connected to the Internet can become a potential classroom (Brodlie, El-khalili, & Li, 2000).

2. *Flexible schedule*: Not only are geographical barriers broken, but also time barriers. The WBLE can be designed to be available 24 hours a day, making it possible for the learners to select the best time (Cook, 2007).

3. *Low cost*: The end user generally owns the training workstation. Furthermore, costs can be reduced using available open-source software standards, such as WebGL (Brodlie et al., 2000).

4. *Distributed servers*: Powerful computation can be performed by a remote server if needed (Brodlie et al., 2000).

5. *Bigger class size*: The application can be used at the same time by a larger set of students than would be possible at a physical simulator or classroom. Theoretically, the class size can be limited only by server capacity and bandwidth (Cook, 2007).

6. *Generality*: A family of applications with consistent methodology can be made available for a range of different training procedures (Brodlie et al., 2000).

7. *Multimedia capabilities*: Web technology provides multimedia support that can be used to add material to aid theoretical knowledge acquisition. Besides the simulation itself, the web-technology facilitates inclusion of tutorials. Also, it is easier to present performance results graphically (Cook, 2007).

8. *Communication and collaboration*: Means of communication between students and/or between students and instructors can be made available to give support to the trainees (Byrne, Heavey, & Byrne, 2010).

9. *Individualized learning*: Materials delivered and feedback can be individualized for each trainee by the application (Cook, 2007).

10. *Easy updates*: Any correction or update shall be done only on the server, and all users will automatically receive the new version (Cook, 2007).

However, as it was mentioned in the case of simulations, even though the web-based technology enables several great opportunities concerning learning environments, the technology alone does not guarantee the learning outcome; good instructional design and planning remain a major priority (Piccoli, Ahmad, & Ives, 2001).

4. WBLE Disadvantages

There is a set of disadvantages related with WBLE as compared to other learning vehicles. The disadvantages of WBLE will be divided into psychological, technical, and those related to the human-computer interaction.

a. Psychological Drawbacks of WBLE

- *Feelings of isolation*: All the flexibility in time and place delivered to trainees also means that they will be frequently studying alone. This situation, when kept for a long enough time, may lead some learners to feel socially isolated; the concept of "long" will depend on the characteristics of each individual. Even with the use of online discussion groups this feeling may persist for those forums that present a different social organization compared to face-to-face interactions in a small group, as in a classroom. (Berry, 2006; Chou & Liu, 2005; Cook, 2007; Fischer, Spiker, & Riedel, 2009; Piccoli et al., 2001). For the training of an SO, AOs play a key role, but a large part of their decision-making process relies on information processed by the members of the STP. Although such information can be artificially generated by the simulation, trainees may feel a lack of human interaction.

- *Frustration*: Positive effects of learner control can be neutralized when a student experiences frustration derived from his or her inability to efficiently operate the application or make effective instructional decisions (Berry, 2006; Chou & Liu, 2005; Hara & Kling, 2000; Piccoli et al., 2001).

- *Anxiety*: When the WBLE is introduced as a new learning method for students who are already used to an old approach, it will require them to navigate through a new learning environment. For those students not used to web technologies, or who have a negative attitude toward this approach, this kind of situation may lead to anxiety. The more a user is comfortable with technology, the more the anxiety will give way to excitement (Chou & Liu, 2005; Fischer et al., 2009; Piccoli et al., 2001; Sitzmann, Kraiger, Stewart, & Wisher, 2006).

- *Confusion*: In the beginning learners used to old forms of interaction may become confused about the adaptations (Gellman, 2005; Hara & Kling, 2000; Piccoli et al., 2001).

- *Reduced interest in subject matter*: Students used to learning "under pressure" may lose interest or feel a lack of motivation in a self-paced environment (Maki, Maki, Patterson, & Whittaker, 2000).

- *Individual differences*: Some students may overestimate their own ability and view less material than desired or skip important components of the lessons in which they are less interested (Lepper, 1985; Reeves, 1993). Individuals also vary the time required to find their best learning ways to take full advantage of learning control (Milheim & Martin, 1991).

- *De-individualized instruction*: Even though one of the main promises of WBLE is the enabling of a more individualized instruction, the opposite can be often found in WBLE that fails to meet the user's individual needs. It is easy for a good teachers to adapt and accommodate to different students' needs, but the web application must be explicitly programmed to do so, which can be a hard goal to achieve (Cook, 2007).

b. Technical Caveats

Other possible drawbacks to WBLE related to the technical aspect of the Internet are:

- *Technical problems*: Frequent technical problems, such as network issues, can amplify existing psychological problems of the users, increasing their frustration with the WBLE (Cook, 2007).

- *Poor instructional design*: A poor instructional design can be more easily noticed in a WBLE due to the absence of an instructor to clarify confusing points and procedures (Cook, 2007).

- *Technology for* technology's *sake*: Developers impressed by the possibilities of a new technology may feel tempted to implement it in a WBLE without considering if it is really useful for the learning context (Cook, 2007).

- *Security vulnerability*: Making content available on the Internet always involves some risks (Byrne et al., 2010).

- *Connection speed issues*: Depending on the application, the connection speed of the user can influence negatively the user experience and the training (Byrne et al., 2010). This is of particular concern for interoperable systems, where one station depends on the input of another, but they may be subjected to different speeds and latency.

c. Human-Computer Interaction Limitations

One of the advantages of large training simulators with physical mock-up instrumentation is that one can train using input and output devices similar to those found in the real system. In the Submarine Multi-Mission Team Trainer (SMMTT), for example, the simulator is a room with the same layout, and in many cases the very same equipment one would find aboard the vessel (Jones, 2008). In that case, adapting a simulation to run over the Internet using only a standard user input devices would represent the loss of most of the mechanical interaction. Although these interactions may

be important for the training of select skills, some training segments can be emulated to work with the forms of interaction available for the user at home. Brodlie et al. (2000) cites how haptic devices can be replaced by the mouse on WBS just by reducing the degrees of freedom on object manipulations. To simulate the force feedback, they used a color code for the user.

The most common forms of interaction available for users at home are:

- Input devices:
  - Mouse
  - Keyboard
  - Webcam
  - Microphone
  - Geographical Location
  - Touchscreen (available on most mobile devices as of 2014)
  - Gyroscopes and inertial sensors (available on most mobile devices as of 2014)
- Output devices:
  - Computer or laptop screen
  - Mobile device screen
  - Loudspeakers
  - Vibration feedback (available on most mobile devices as of 2014)

In WBS design, using creativity and the results of scientific studies, developers can simulate the human-machine interactions present in real systems, adapting those interactions to be performed with the devices available for the user. Those adaptations would allow the simulation to put users in contact with most of the interactions they will later experience in the actual system. However, it is important to avoid the introduction of the negative training, using a form of interaction too different from that of the real environment. In some cases, it might be better to design the WBLE to perform only PTT.

d. Health Issues

As is common for virtual environments, users may experience some cyber-sickness (Stanney, Kennedy, & Drexler, 1997). This condition can be aggravated by the fact that the virtual environment movements in a WBS do not accompany actual movement of the user's body. Designers of WBS should employ different techniques to reduce those undesired effects and make the experience more comfortable for the learner. Other possible health issues are the ones common to normal use of the Internet, such as addiction, depression, etc., which are out of the scope of this thesis.

5. Pedagogical Factors of WBLE

Most authors assume that WBLE learning philosophy and the interactive nature of that software are aligned with the constructivist theory (Piccoli et al., 2001). The constructivist learning theory asserts that individuals take more advantage of learning when they discover things by themselves, while controlling the pace of learning and using the support of instructors only when it is needed. This view is in opposition to the objectivist approach that assumes the pre-existence of the knowledge presented to the student by the instructor, and that the instructor is the owner or controller of that knowledge (Ahmad, Piccoli, & Ives, 1998).

When the effects of WBLE are being considered, two important pedagogical concepts frequently come into play: learner self-efficacy and learner control. Bandura (1986) defines self-efficacy as:

> … people's judgments of their capabilities to organize and execute courses of action required to attain designated types of performances. It is concerned not with skills one has but with judgments of what one can do with whatever one possesses. (p. 391).

The main concern of self-efficacy is the judgment of what the person can do with what he or she possesses. In the context of WBLE the importance of self-efficacy may indicate the propensity of the learners to actually apply what they have learned. Higher levels of self-efficacy have important influence on individuals' behavior (Bandura, 1986). According to Compeau and Higgins (1995), self-efficacy can influence the learner's choice about the behavior to undertake, effort to exert, and persistence in attempting

those behaviors. Self-efficacy also helps learners to adjust and handle an unfamiliar learning environment.

Learner control is the degree of freedom that students can exert over the pace, sequence, and content of instruction in a learning environment (Milheim & Martin, 1991). Learner control is important because it is believed to increase the learner's satisfaction, consequently also increasing the learner's self-efficacy. Learner control has a potential to turn into satisfaction, enjoyment, and confidence, and it makes students feel more efficacious (Taipjutorus, Hansen, & Brown, 2012). Technology mediated learning environments improve both the student's evaluation of the learning experience and his or her achievements. It also helps to increase teacher-student interaction and make the learning process more student-centered (Piccoli et al., 2001).

6. Adaptive and Intelligent Tutoring Systems

Web-based simulations convey to the learner a high flexibility, which mainly derives from the fact that they can be accessed anywhere, anytime, depending only on the user's schedule. From this same feature, however, derives one of the biggest caveats of training systems over the Internet: a lack of instructors' attention to monitor students' progress. Although simulations are undoubtedly useful as training tools, the simulations themselves are not sufficient to guarantee a valuable and thorough learning experience. If only the scenario is presented, without doctrinal and procedural guidance, even an experienced user can become lost. Simulations designed for training purposes are more effective when they come alongside with instructional features embedded in them (Salas & Burke, 2002). Also, the effectiveness of a training simulation is improved when it provides an assessment of performance, not only to ease the evaluation of the instructor and avoid subjectivity, but also to provide diagnosis on skills deficiencies (Salas & Burke, 2002). A powerful approach to training is one-on-one tutoring (Bloom, 1984), in which one instructor follows one student closely, correcting weaknesses and reinforcing strong points. Most of the strength of this approach, in comparison to group training or self-tutoring, comes from the fact that human instructors are able to scaffold the student during the learning process and give feedback to encourage the student's progress

(VanLehn, 2011). Nonetheless, this teaching style is generally not feasible in the field of military training, where normally there are only a few instructors to teach a relatively big group of trainees within a limited time frame. On the other hand, since a web-based application is frequently a lonely adventure, it carries all the caveats of any self-education experience. Unguided practice can often lead to negative training, loss of focus on the right behaviors, bad distribution of time among the various aspects of training, and diminishing of training transfer to the job (Salas & Burke, 2002). Those characteristics give a clue that perhaps the use of intelligent tutoring systems (ITS) can be a leveraging tool for WBS. Some aspects of the one-on-one tutoring approach can be reproduced and improved in computer-based training (CBT) using ITS. ITS can help to fix some of the main drawbacks of CBT and self-tutoring (Landsberg et al., 2012). ITS is meant to provide immediate and customized instruction or feedback to learners (Psotka, Massey, & Mutter, 1988), while delivering adaptive learning in which the training interventions can be tailored to individual constraints, aptitudes, and preferences. The review conducted by Van Lehn (2011) in several experiments about the effectiveness of ITS, has found that ITS is nearly as effective as one-on-one tutoring, with an effect size of $d = 0.76$ for ITS in opposition to $d = 0.79$ for the one-on-one approach. It is indispensable to emphasize, though, that the studies reviewed covered several different types of skills and audiences. The correlation between specific types of skills and the efficiency of ITS training was not the focus of Van Lehn's study.

7. WBLE Effectiveness Findings

There are several studies that compared WBLE and e-learning with the traditional classroom environment. Chou and Liu (2005) in their research with junior high school students found that students using a WBLE reported higher learning performance, higher computer self-efficacy, higher satisfaction, and higher levels of learning climate. Their field experiment focused on the effectiveness of WBLE for basic information technology skills training. In another research conducted by Sitzmann, Kraiger, Stewart, and Wisher (2006), traditional classroom and WBLE were found to have the same effectiveness for teaching procedural knowledge and for teaching declarative knowledge when the same instructional method was used for both, highlighting the overriding importance of

instructional design. However, in the same study, the instruction through WBLE was found to be 19 percent more effective than classroom instruction for teaching declarative knowledge when trainees received feedback in long courses and when learner control was provided.

WBLE includes an overarching range of instructional styles and cannot be treated as a single entity (Cook, Garside, Levinson, Dupras, & Montori, 2010). WBS is only one of the instructional styles of WBLE. WBS can potentially merge the advantages of WBLE and simulations. In a meta-analysis of the instructional effectiveness, simulation games were found to deliver 14 percent more effectiveness for procedural knowledge teaching and 11 percent more effectiveness for declarative knowledge, with 9 percent more retention, and 20 percent higher self-efficacy, showing that this modality of teaching has the potential to leverage the teaching of work-related knowledge and skills (Sitzmann, 2011).

Although several studies have found evidence about the effectiveness of WBLE for teaching, a question always to be considered is whether the increased effectiveness is accounted for by the characteristics of WBLE or by the suitability of the instructional method when applied via WBLE. Clark (1994) states that, although some media may be more cost-effective, the final effectiveness of learning is not influenced at all by the media, which works only as a vehicle. Reeves and Reeves (1997) complement this view, listing ten dimensions that will actually influence the effectiveness of interactive learning in WBLE:

1. *Pedagogical Philosophy*: The adoption and application of an instructivist or constructivist epistemological approach.

2. *Learning Theory*: The predominance in instructional design of either a behavioral or cognitive theory. Behavioral theory focuses instruction on shaping the subject's behavior to identified desirable behaviors through stimuli, responses, feedback, and reinforcement. The cognitive theory puts more emphasis on internal mental states (mental models, skills, schema, rules) than on externally manifested behavior.

3. *Goal Orientation*: The instructional goals can range from sharply focused to general goals.

4. *Task Orientation*: Whether the learning is more geared to academic or authentic (practical) tasks.

5. *Source of Motivation*: Can be predominantly extrinsic, meaning that the motivation to learn comes from outside the learning environment, or intrinsic, when the motivation is built by the learning environment.

6. *Teacher Role*: Ranging from a didactic (direct participation) to facilitative.

7. *Metacognitive Support*: Whether the learning system is supportive or not; "the skills one has in learning to learn" (p. 62).

8. *Collaborative Learning*: WBLE can be designed to ignore or promote collaborative learning.

9. *Cultural Sensitivity*: The system may be insensitive to or respectful of cultural implications of the tasks and subject matters covered.

10. *Structural Flexibility*: Whether the system is fixed or open regarding time and/or place.

The adjustment of each dimension of this model for each training need would lead to the optimization of the learning effectiveness (Reeves & Reeves, 1997).

D. CHAPTER SUMMARY

When deciding about the introduction of a novel technology for training support, one should keep in mind that it is the way in which the instruction is implemented while using that technology and not the technology itself that determines the improvement or deterioration of learning outcomes (Clark, 1994; Piccoli et al., 2001). Although the appropriateness of a WBS depends on factors like instructional context, objectives, and instructional approach, the technology enables the use of tools to aid learning that would be impossible in other environments or with other type of technology. Flexible WBS can be adapted to supplement thorough simulations. This approach can be used to address isolated skills and abilities using the browser and reduce the time necessary for training ashore. The use of PTT is a key approach for WBS. Creative solutions can be deployed to replace missing interactions available on the original simulator. The absence of instructors can be remedied with the application of tutoring powered by artificial intelligence and help avoid negative learning. Submarines are complex and very

expensive weapons, and their operation requires very well-prepared people. Not paying due attention to the training of submarine personnel risks the loss of lives and assets. Simulators have substantially enhanced the quality of training, but they have constraints related to their cost and availability. Web-based simulations, though, if well designed and applied, could complement the training process that use simulations and complement or replace part of the time needed for classroom instruction. WBS is especially useful as a tool to help trainees develop the skills that they would otherwise need to practice without any help. Regarding the time of use of WBS, this type of training solution can be used before, during, or after the programmed career courses or training sessions. If used before the courses, they can prepare the students with basic skills and solve minor deficiencies upfront, so that students' time in the training facility will be optimized. If used during the career courses, they can teach or reinforce necessary knowledge. If used after the student has had formal training, those systems keep the student up-to-date with his or her abilities while offering a flexibility of time and place where training will be organized. It is important to note that adapting an existing simulation to use the support of WBLE might require ongoing revision to minimize the effect of disadvantages and take full advantage of the strong points that the web-based approach offers.

IV. TASK ANALYSIS

The goal of the task analysis was to provide a detailed description of the tasks done by an AO and to identify the parameters that would guide the development of the WEBS. This task analysis also aimed to provide the answers to research questions 2 and 3:

Question 2. What are the main KSA necessary for the performance of the AO and his role in a submarine?

Question 3. Which of those KSA could be improved with the help of a WBLE, without the direct help of an instructor and outside the classroom environment?

The execution of the task analysis is performed in three steps: description of the missions, analysis of the tasks involved in the missions, and selection of relevant information from the task analysis.

In the first step, using the AT from the BNSS as an example, the main training missions performed in training sections at that simulator are described. The goal was to build an overall vision of the tasks that are usually trained at these simulators.

Next, a single mission is selected to perform the task analysis. The Cognitive Task Analysis (CTA) methodology is used to decompose the mission in tasks, identifying goals, tasks, and sub-tasks, MOP, and the KSA required to perform those tasks.

The last step used information generated by the CTA and determined which set of tasks could be implemented in the WEBS system in the form of PTT.

The main point considered for planning the design of WEBS is that it is impossible to replicate all the interfaces available at the AT in the users' home. Thus, the tasks were detailed and subdivided, having the KSA identified to enable their training separately, following the PTT approach.

A. DESCRIPTION OF THE MISSIONS

The first step consisted of understanding the missions performed in the original simulator. This section describes the main missions usually trained in courses administered at the AT of BNSS. The objective is to yield a holistic view of the context in which the tasks are performed.

The ATs are modular simulators built in a facility at BNSS. They provide a mock-up of the equipment found in a submarine Control Room. There are four rooms that compose each facility. The first room houses only the computer processors that generate input signals for the simulation, acting the role of sensors. The second room is the instructor management room where the operators can control the simulation and record the trainee's performance. There is also an attached classroom used for briefing and debriefing of exercises. Finally, there is the simulator room which represents a reconstruction of the Control Room of a "Tupi" or "Tikuna" class submarine. All the stations manned by the members of the STP and respective equipment replicate the same layout found in the submarine Control Room (Figure 7). The AT can provide team training for an entire STP of a submarine, and it also has a permanent crew to man it during courses and specific trainings when the training is focused only on the AO. The role of the key elements of the STP is summarized in Table 3.

Table 3. Main responsibilities of the key members in the Section Tracking Party.

Team Member	**Responsibility**
Executive Officer (XO)	Manages the team, combines the solutions of all stations and generates a general STP solution
Sonar Supervisor	Manages detection, tracking, classification, and solutions provided by the Sonar Systems
Combat Systems Supervisor	Manages the combat systems and the solutions provided by them
Contact Evaluation Plot (CEP) Supervisor	Manages solutions of Target Motion Analysis (TMA) using the CEP.
Plotting Supervisor	Manages the geographical plotting and the TMA using the plotting table methods.

Some of the missions usually trained at the AT are:

1. Go-Deep Range Exercise (GODEX)
2. Anti-surface warfare
3. Secondary Operations
    - Intelligence, surveillance, and reconnaissance (ISR)
    - Mine warfare
    - Special operations
4. Evolution to Periscope Depth
5. Anti-submarine warfare (Sub x Sub)

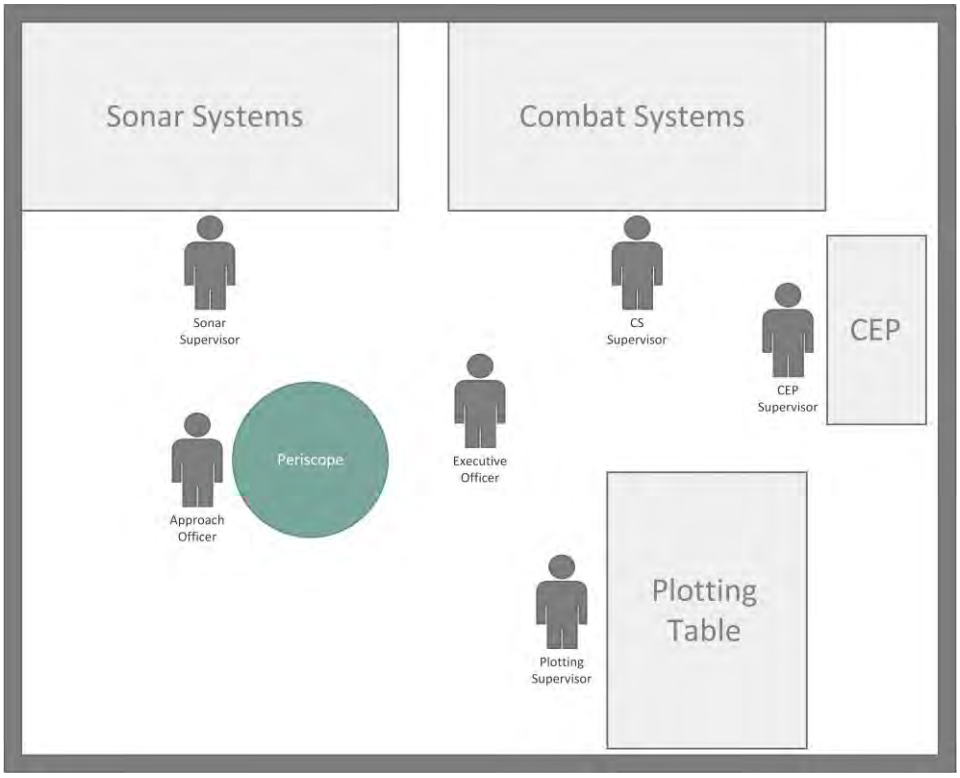

Figure 7. Positioning of the Section Tracking Party in the Control Room and at the Attack Trainer Simulator.

1. Go-Deep Circle Exercise (GODEX)

The GODEX is used to train and assess AOs on their mastering of the concepts of submarine safety in PD. This training, also known as "eyes-only," is generally applied as a preliminary step to certify that the trainee is able to employ PD attack rules and keep the submarine safe in more complex operations. In order to exercise most of the precepts of safety, it exposes the trainees to extreme and highly stressful situations. Such extreme situations involve the approximation of ASW ships to the submarine in varied configurations; sometimes they are made to be passing close to the GDC limit, and sometimes crossing it and passing over the submarine. An example of a run with two contacts is shown in Figure 8.

The AO is required to keep SA all the time with the lowest possible collection of data with the periscope and following strict procedures to diminish mast's exposure. If the trainee judges that the safety of the submarine is compromised by the proximity of a contact, the only maneuver allowed is to descend to SD, wait for the contact to pass over the submarine, reassess the situation, and then, if the situation allows it, evolve to PD.

The trainee is not allowed to change the course or speed of the submarine during the exercise. While this situation is very unlikely in a real combat scenario, the training of all the concepts of safety at PD does not happen in just one exercise; a series of training sessions are used to exercise and assess the trainees' mental quickness, emotional control, and cognition capability under stress. Another objective is to promote the trainees' self-confidence and force them to make contact with their own limitations and capabilities. This exercise is performed in the same manner both at the simulator and at sea in the real environment.

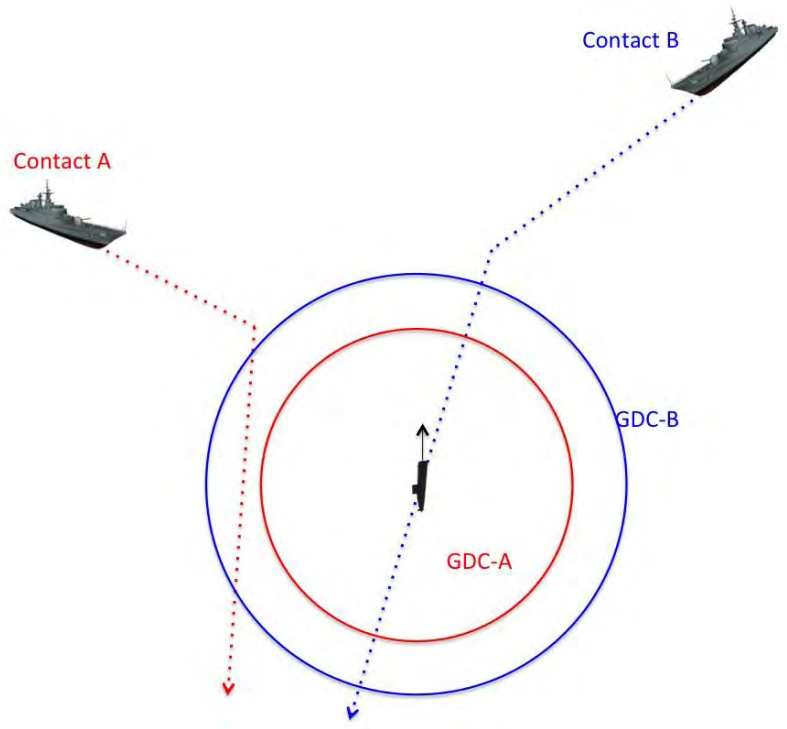

Figure 8. Example of relative motion plot of a GODEX run with two contacts.

The exercise begins with the submarine at PD, crossing a SPA where the traffic of surface ships is expected. The trainee assumes the AO role, and is assigned the task to maintain the submarine at PD as long as possible, without jeopardizing the submarine and allowing the surface contacts to reach its GDC. All calculations must be made mentally by the AO using several stopwatches to control time for each contact and for the ARL interval.

2. Anti-Surface Warfare

The main mission for a conventional submarine is to attack a surface ship, generally the High Value Unit (HVU) of an enemy task force like a war vessel with high strategic relevance. Due to the importance of these ships and their relative defenselessness, HVUs are generally escorted by ASW ships, aircrafts and even hunter-killer submarines, making it very challenging for the submarine to approach and attack. These escorts are all endowed with accurate sensors and powerful anti-submarine weapons. If the personnel of the submarine want to successfully execute an attack, the

submarine must be previously positioned to approach the objective target at the right time and at the right place, while at the same time does its best to avoid detection by ASW units. This kind of mission does not necessarily involve operations on PD.

3. Secondary Operations

The missions of ISR, mine warfare, and special operations are henceforth named secondary operations. The approach phase of these missions is quite similar to that of ASW. These missions will generally differ from ASW only in terms of the final objective. Since the main interest of this thesis is on the approach phase; the particularities of each of these missions will not be detailed.

4. Evolution to Periscope Depth

The PD evolution is a procedure composed of a series of actions executed to move the submarine to PD, coming from a deeper depth. To evolve to PD, the trainee, in the role of a watch officer, commands a series of procedures to collect information about surface contacts and the surrounding environment, and then chooses the best course to take the submarine to PD. Almost all tasks are executed with the submarine below PD, and therefore they are outside of the scope of this thesis.

5. Anti-submarine Warfare

This mission involves hunting of another submerged submarine. All the actions are generally taken with the submarine transiting deep that is done without the use of the periscope; as such it is outside of the scope of this thesis.

B. COGNITIVE TASK ANALYSIS (CTA)

The GODEX mission was selected for the CTA, because it is the most intensive and comprehensive mission regarding the training of periscope techniques. CTA encompasses a series of methods that study and describe the knowledge and reasoning used while performing some tasks. It is useful when it is necessary to elicit the organization and structure of information that people use, to understand how they think,

what they know, and what they seek to understand better (Crandall, Klein, & Hoffman, 2006).

The CTA was performed to pinpoint the tasks that could be simulated in WEBS, to list the critical cues that should be provided, and the set of KSA required for each task. As important as it is to identify the tasks to be simulated, it is also important to identify and prune the tasks that are not recommended to train on a WBS because they are too complex, or they could lead to negative training due to the lack of appropriate interface or sensory cues. A good example of tasks not intended to be trained are those related to the operation of the periscope controls. Although it is important for the trainees to get used to these controls, these controls are very specific to each equipment type, and should be trained on a replica or at the equipment itself. The attempt to virtually recreate it in WEBS could lead to negative training transfer.

Most of the sources of documentation for the techniques used in these tasks are classified. This fact has limited considerably the scope of the CTA reported in this thesis. The task analysis will only reproduce the level of detail that can be found in non-classified sources. As the usability study was performed publicly, only a part of the ARL task was selected to be implemented in WEBS and published for the usability study.

The CTA was performed in four steps, using the same methodology successfully employed by Moraes (2011) for the design of a game-based shiphandling simulator:

1. Detail and decompose tasks performing a Hierarchical Task Analysis (HTA)
2. Generate a Critical Cues Inventory (CCI)
3. Select tasks to be trained
4. Identify MOP

The steps are detailed in the next sections. The sources used were the observation of videos of trainees executing the GODEX mission, and the analysis of all documents.

1. Hierarchical Task Analysis (HTA)

The first step consisted in performing a HTA. The HTA is a way of representing hierarchically the goals and sub-goals of a system, highlighting its operations and plans, to allow an extended analysis (Stanton, 2006). Performing a HTA helps to identify the cognitive tasks driven by these goals (Annett, 2003). Following the methodology and notation proposed by Stanton (2006), a simplified diagram for the GODEX mission, with the hierarchy of tasks and plans of execution, is summarized in Figure 9.

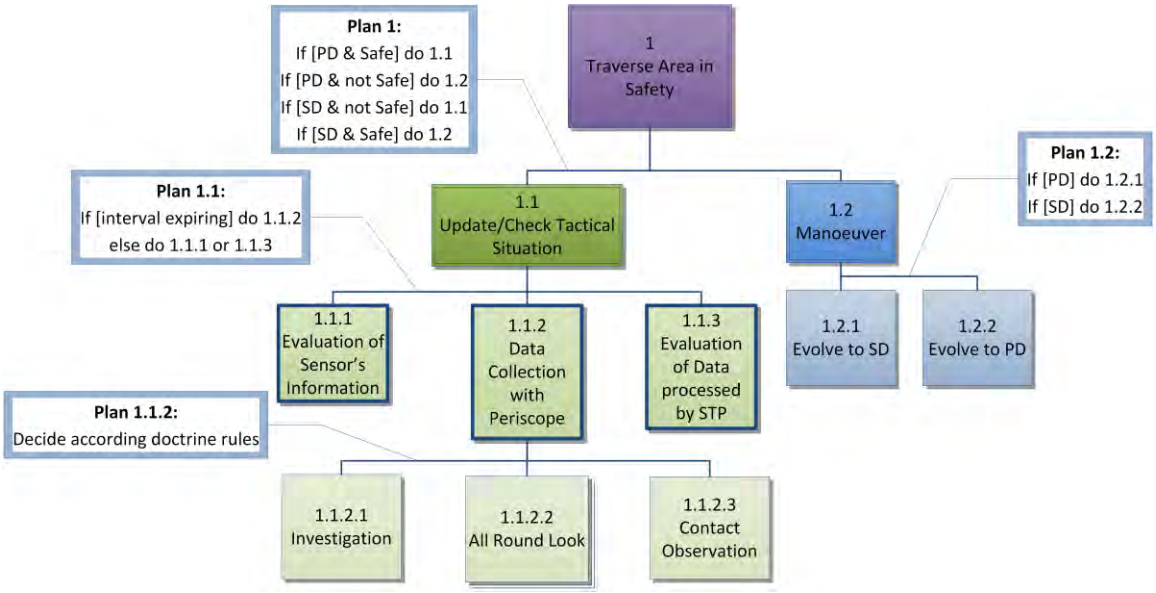

Figure 9. Hierarchical tasks tree diagram for the GODEX mission.

The procedural diagram in Figure 10 emphasizes some points of decision in the mission, detailing it up to the third level of sub-tasks.

A detailed description of the tasks from the HTA diagram was implemented in the tabular form. The detailed description includes valuable information about the cognitive processes and sensory perception performed by the AO, also stressing some key required KSA. Most of the tasks rely on doctrinal rules based on classified sources.

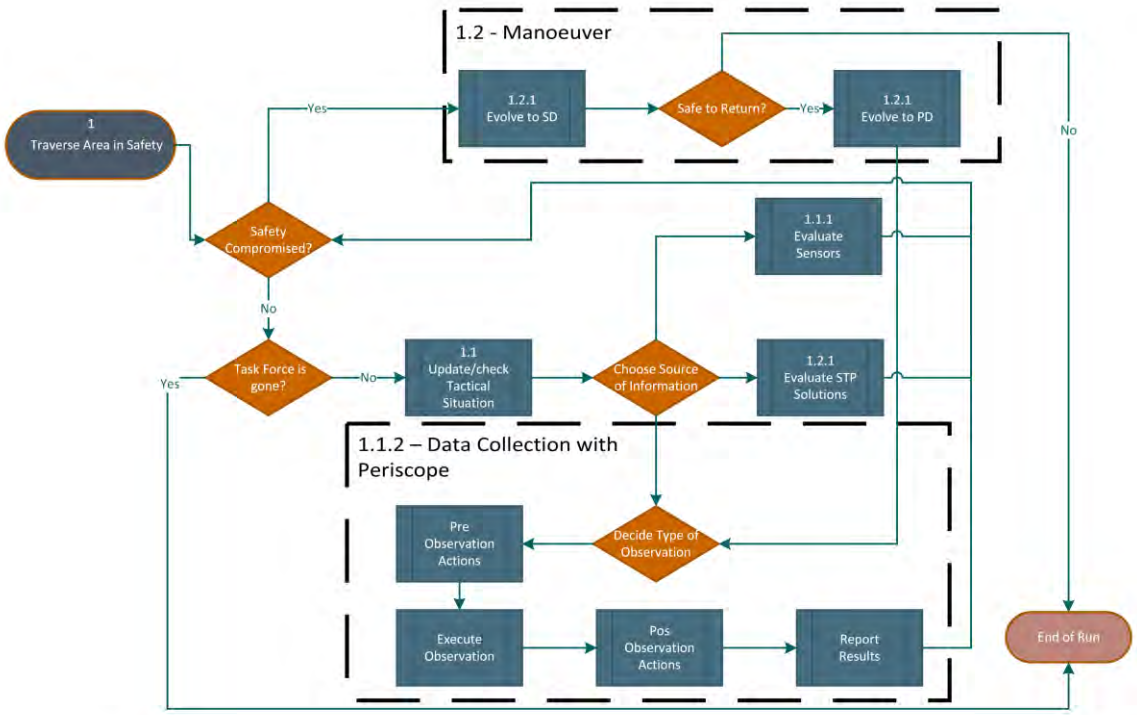

Figure 10. Summarized procedural diagram for GODEX mission.

Due to its simplicity and lack of classified information, the ARL task (task 1.1.2.2) was selected as an example for implementation in WEBS, and it is used for the usability study. Figure 11 shows the hierarchical diagram of this task. The detailed tabular form for this task is reproduced in Table 4 (note that only the tasks that do not involve any classified source are reproduced in this table).

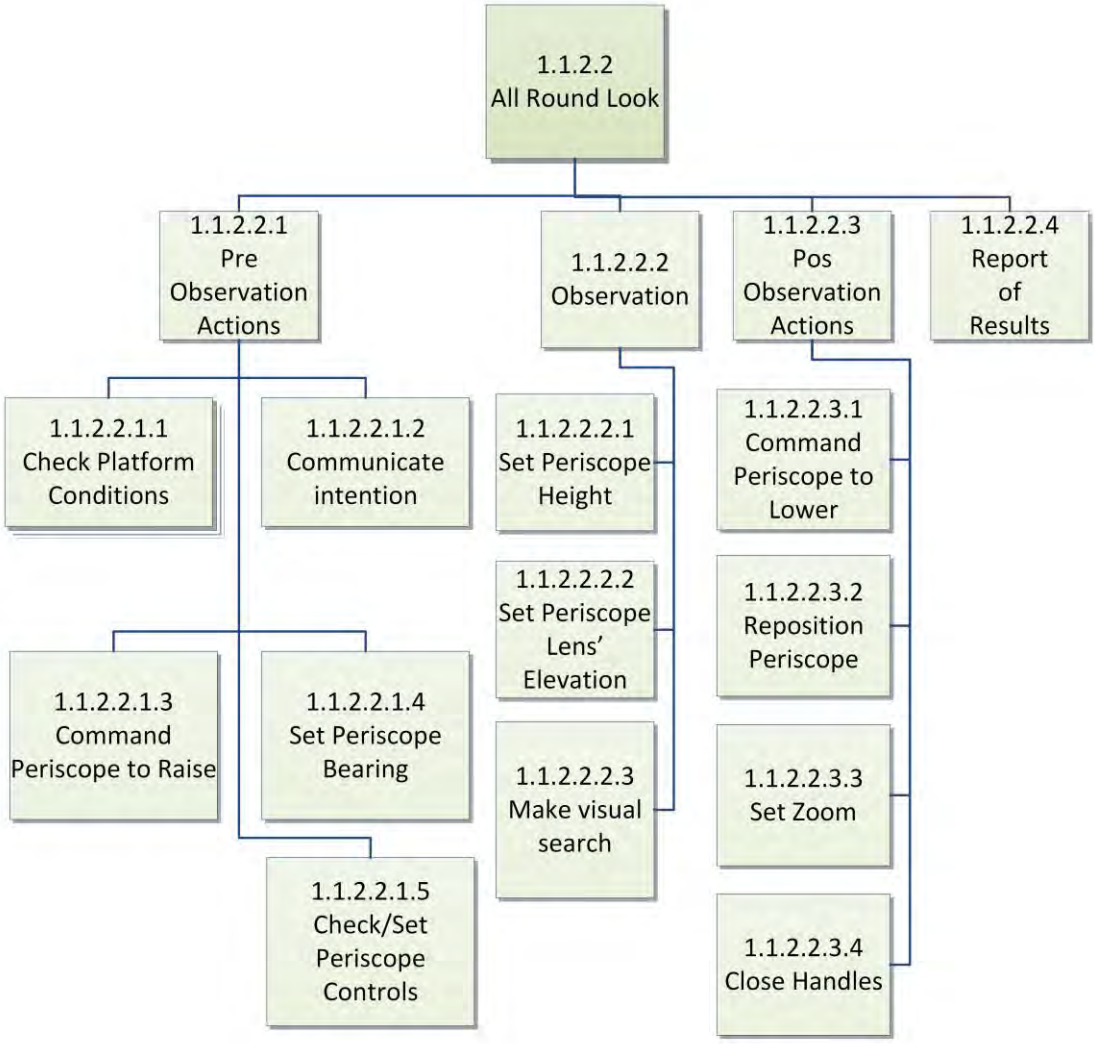

Figure 11. Hierarchical diagram of sub-tasks' tree for the ARL task.

Table 4. Detailed description of tasks.

Step	Task	Task Description	Remarks
1	Traverse Area in Safety	This is the overall goal. The AO must traverse an area in which there will be surface ships transiting. For the version considered in this study the trainee is not allowed to change the submarine's course.	During the traversal the trainee must keep the periscope lowered for as long as possible without risking the safety of the submarine.
1.1	Update Tactical Situation	AO performs the most adequate technique to obtain information about the surrounding tactical situation.	The AO must assess the source of information to be evaluated based on his mental model of the situation and on the time available according to his control of time.
1.1.1	Evaluation of Sensors' Information	AO obtains information of the contacts straight from sensors' displays or from supervisors.	AO checks if the information from sensors is consistent with his model of the situation.
	Evaluate data processed by STD	AO checks the STD solutions managed by the XO.	AO compares solutions with his own mental models
1.1.2	Data Collection with Periscope	AO obtains information of the contacts performing a periscope observation.	AO must judge which type of periscope observation is appropriate based on the data he needs to obtain and the time he has to do it.
1.1.2.2	All Round Look	AO performs an ARL.	
1.1.2.2.1	Pre-Observation Actions	Set of tasks performed to put the periscope ready for an observation. Comprises all actions taken from the decision to raise the periscope until the AO puts the eyes on the eyepieces to begin the observation.	

Step	Task	Task Description	Remarks
1.1.2.2.1.1	Check Platform Conditions	Conditions of the submarine to be checked every time before the periscope is raised.	Each condition should be checked "at a glance." Depending on conditions like the depth of the keel, speed over ground, or hull inclination, the AO may decide to not raise the periscope until corrections are made on the platform conditions.
1.1.2.2.1.2	Communicat e intention	After deciding that all conditions allow for periscope raising, the AO announces orally to STD what kind of observation he will do.	
1.1.2.2.1.3	Command Periscope to Raise	AO commands the periscope he will use to be raised	After the AO commands the periscope to be raised, the CEP supervisor orally announces the estimated bearing of known contacts.
1.1.2.2.1.4	Set Periscope Bearing	AO turns the periscope to the bearing where he expects to begin his observation.	Assessing his SA and the information just received from CEP Supervisor, the AO decides what is the best bearing, according to safety rules, to begin the ARL. As periscope comes closer to the floor limit, the AO crouches. As the periscope handles become reachable near the floor, the AO turns it to the selected bearing.
1.1.2.2.1.5	Check/Set Periscope Controls	AO manually sets the periscope controls while it is being raised	To save time, the AO must crouch and do these settings as soon as he can reach the periscope controls near the floor, while he still cannot reach the eyepieces with his eyes.

Step	Task	Task Description	Remarks
1.1.2.2.2.5.1	Check/Set Zoom	The periscope zoom must be set in accordance to the type of observation to be made.	AO sets the periscope to the lowest zoom to perform an ARL.
1.1.2.2.2	Observation	Execute Observation	AO execute chosen type of observation.
1.1.2.2.2.1	Set Periscope Height	AO sets the periscope height.	AO evaluates, according to his own height and sea state, a height for the periscope in which it is possible to execute the observation, exposing just the sufficient amount of mast.
1.1.2.2.2.2	Set Periscope Lens Elevation	AO uses periscope controls to set the best lens elevation to execute the search.	AO must recall safety doctrine to adjust it, considering expected threat.
1.1.2.2.2.3	Make visual search	AO turns the periscope 360º, visually scanning the horizon looking for contacts.	AO must focus total attention to this search.
1.1.2.2.3	Post Observation Actions	AO takes action to lower the periscope just after finishing the observation procedure.	According to the current tactical situation, the AO must predict what is his next step, and decide to lower the periscope all the way down or just enough to break its exposition (flood the periscope) allowing for a faster raising afterwards.
1.1.2.2.3.1	Command Periscope to Lower	AO commands orally to lower or “flood” the periscope.	AO commands orally to lower or “flood” the periscope

Step	Task	Task Description	Remarks
1.1.2.2.3.2	Reposition Periscope	While the periscope is being lowered, the AO quickly turns it to the start bearing of the next observation.	Having a refreshed SA after the execution of an ARL, the AO must plan one step ahead, choosing the next periscope to be done, and setting the periscope bearing on the bearing to begin the next observation. This movement must be done quickly and without looking at the eyepieces.
1.1.2.2.4	Report Results	AO recalls from memory the data about the observation, calculates and orally reports the results.	AO recalls from memory each contact or important new information collected during the search. For each contact, he should report all information gathered, such as estimated bearing, classification of the contact, AOB, and respective course.

2. Critical Cue Inventory (CCI)

The CCI is a collection of informational and perceptual cues found to be critical cognitive probes to support decision (Klein, Calderwood, & MacGregor, 1989). The list contains detailed descriptions of the perceptual and judgment cues (Hoffman, Crandall, & Shadbolt, 1998).

From the tree of tasks subordinate to the ARL task, the most important steps have their CCI reproduced on a table. Predominantly mechanical tasks, such as 1.1.2.2.2.1 (set periscope height) and 1.1.2.2.1.5.1 (set zoom), were not reproduced here, for they are outside of the scope of this thesis.

Table 5. Critical Cue Inventory for making a visual search.

Step: 1.1.2.2.2.3 – Make visual search	
Cue	Description
Visual of disturbance on the horizon	AO perceives the image of a vessel, aircraft, or other contact of interest diverging from the sea and sky visually.
Periscope built-in display	AO looks to the relative and true bearing in which the contact was seen.
Angle marks on periscope reticle	AO memorizes the angle covered by the contact image in the lens.

Table 6. Critical Cue Inventory for reporting results.

Step: 1.1.2.2.4 – Report Results	
Cue	Description
Memory of global situation	AO reports orally: (1) The number of contacts sighted. (2) Any abnormal condition. (3) Weather conditions, if convenient.
Memory of bearings	AO recalls from memory the bearings in which contacts were sighted, then mentally organizes them around his mental image of the situation. The AO reports the sightings either by true bearings or by the relative position from the submarine.
Memory of contact image format	For each bearing, the AO recalls from memory the contact sighted. Evaluating the memorized image, he extracts all possible information: (1) If close enough to see the visual characteristics of the contact, AO compares with the models in his memory and makes a classification of the contact. If in doubt he adds a degree of uncertainty (possible, probable). (2) From his previous knowledge of the contact format and size, AO compares the image just seen and has a first estimate of the distance of the contact. (3) If close enough to see the orientation of the contact, the AO estimates the contact's AOB, and then calculates and reports the contact's course (as shown in Figure 4), and distance to route.
Memory of angle covered by the contact's image	If applicable, the AO calculates mentally a more accurate estimate of distance for the contact using the angle covered by the contact as well as the memorized information about the height of that contact's structure.

C. SELECTION OF TASKS

The PTT approach and the insights gathered from the review made in Chapter III were used for this thesis. For the selection of candidate tasks to be implemented for training in WEBS, the following criteria were applied on the total set of tasks detailed in task analysis:

1. Absence of procedures or MOP cited solely in classified sources
2. Absence of procedures exclusively related to the operation of the real equipment
3. Existence of complex cognitive process in the task likely to be trained on a WBS
4. Existence of pre-required knowledge likely to be taught using a WBS

Following these criteria, the sub-goals 1.1.2.2.2.3 (Make visual search) and 1.1.2.2.4 (Report Results) were selected for implementation of a demonstration version of the software; the same system was used in the usability study.

D. MEASURES AND STANDARDS OF PERFORMANCE

During the execution of exercises on AT or aboard a submarine, the instructors constantly evaluate the performance of trainees, providing feedback and corrections when appropriate. The importance of feedback and tutoring in WBLE was commented on in Chapter III. In regard to those aspects, some common MOPs were established for the ARL task, with respective standards for the 100 percent scoring (Table 7). For this implementation, the standards of performance are hypothetical and do not aim to reflect actual measures of performance used in the real case. Those standards can be easily fixed to match real requirements.

Table 7. Measures of performance for the All Round Look Part-Task Training.

Indicator	**Description**	**Metric**	**Standard**
Time of procedure	Time taken from the beginning of the procedure until the trainee finishes the horizon scanning.	Seconds	Between 20 and 30 seconds.
Periscope Lens elevation	The angle of elevation of the periscope lens during the movement.	Proportion sea/sky on lens	2/3 of sky, 1/3 of sea.
Horizontal angle covered	If the trainee completes the 360 degrees of visual scanning.	Degrees	Greater than or equal to 360º.
Zoom level	If the trainee uses the correct zoom level	Magnification	Equal to 1.5x.
Detection of contacts	The amount of visible contacts actually detected by the trainee	Count	Equal to the amount simulated.
Contact classification	Correct visual classification of the contact		
Angular orientation	The correct report by the trainee of the angular localization of each contact	Angle (bearings)	Equal to the actual simulated bearing, plus or minus 5º.
Estimation of distance	The estimation of distance made by the trainee of each contact	Yards	Equal to the actual simulated distance plus or minus: - 100 yards, for contacts closer than 5000 yards. - 500 yards for contacts beyond 5000 yards.
AOB	Correct estimation of the AOB	Degrees (180º for starboard and port)	Equal to the actual simulated orientation of the contact, plus or minus 5º.

E. LEARNING OBJECTIVES

Learning objectives are of paramount importance for the design of any instructional system. The established learning objectives should be used to help guide the definition of requirements and development of the instructional tool. The results of task analysis identified the following learning objectives for the ARL task:

1. Teach trainees the correct practices and the execution of the ARL task.
   - Correct timing for the horizon scanning
   - Correct lens elevation and setting the zoom
   - Correct way to start and finish a scanning, covering the 360º
2. Help trainees develop memorization skills to build a mental model of the tactical situation surrounding the submarine.
3. Teach trainees about the cues needed for estimation of the visual distance between the contacts.
4. Help the trainees recognize and classify contacts visually.
5. Help trainees develop the ability to estimate the AOB of contacts.
6. Teach the trainees the methods for calculation of course of the contact and distance to route using the estimated AOB.

F. REQUIREMENTS

Based on the insights gathered by the task analysis performed, the following requirements were established for WEBS.

1. Purpose

The main purpose of WEBS is to provide a web-based simulation using a virtual environment that represents the tasks normally executed by the SO when using periscopes. WEBS is expected to help SOs develop necessary KSA needed for the practice of operations on PD, preparing them for the execution of missions of this kind aboard the submarine or in the simulators.

2. Users Demographics

The primary users for whom WEBS is intended are Junior SOs in their first contact with this type of mission. These users are generally Lieutenants Junior Grade, male, with ages ranging from 25 to 30 years, with previous basic classroom instruction in the theoretical concepts of PD safety rules.

The secondary users for WEBS are the more experienced SOs, who have already had some periscope training, and have more solid knowledge about the periscope techniques. Those users are generally Lieutenants, male, with ages ranging from 28 to 45 years.

3. User System Environment

As a web-based system, WEBS must be able to run in most Internet browsers, in desktop and laptop personal computers from a large range of configurations; the desire is to reach the capabilities of the average Internet user. The software is not intended for use under an instructor's supervision.

4. Limitations

WEBS was not designed to provide the following capabilities:

- Mobile training
- Full mission training
- Extremely accurate and realistic representation of the sea surface
- Intelligent Tutoring System
- Accurate representation of periscope equipment controls

5. Functional Requirements

The requirements about the specific behaviors and functions expected from WEBS are:

1. Simulation of the visual of a periscope screen
2. Simulation of the main information available at a periscope screen for the user
    - True bearing of the periscope
    - Relative bearing of the periscope
    - Stadimetric distance
    - Crosshairs
    - Range divisions in minutes of arc
    - Lens magnification (zoom)
3. Simulation of the horizontal and vertical rotations of the periscope lens
4. Simulation of periscope zooming in and out
5. Simulation of the periscope stadimeter
6. Simulation of the sea surface and the environment
7. Simulation of common ships and aircrafts models
8. Simulation of movements of naval units
9. Simulation of the ranging with the stadimeter
10. Instructional system
11. Detection and evaluation of MOP
12. Feedback system

6. Non-functional Requirements

The requirements for WEBS in its more general aspects, not related specifically to its functionality, are:

1. Intuitive user interface, allowing self-learning
2. Self-explanatory setup
3. Built-in instructions for quick familiarization with the user interface and mission
4. Use only input devices available in personal computers

5. Run the software via most common web-browsers to date (Google Chrome, Mozilla Firefox, Safari, Internet Explorer, and Opera)
6. No need for plugin software installations

G. CHAPTER SUMMARY

The CTA performed for the common missions of submarines on PD offered the insights valuable for understanding the tasks performed by an SO and adapting them for the WBS training simulation.

Once the CTA was performed, a deeper understanding of the hierarchy of sub-tasks allowed the selection of the best tasks to be implemented in a WBS. The list of perceptual cues for each task served as a guide for the definition of the design requirements for the simulation. The learning objectives, an indispensable part of any instructional system, were defined from the knowledge of the hierarchy of tasks, the listing of critical cues, and knowledge about the overall task objectives.

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V. PROTOTYPE DEVELOPMENT

This chapter describes the process of development of WEBS, based on the requirements defined in the previous chapter. The original intention of this thesis was the full development of a WBS to help SOs training through PTT, to fill the gap between classroom teaching and simulator training. However, most of the tasks performed at a periscope simulator contain procedures and doctrinal rules that are classified. This fact has limited the boundaries of what can be implemented in the application and released. As explained in the previous chapter, the ARL task was selected to design and develop WEBS, a sample WBS that could be publicly tested on its usability.

Although the ARL task was the only one submitted for usability testing, the framework developed for it can be used for training of other tasks, just by modifying the scenario settings.

A. TECHNOLOGY

This section describes the web technologies used for development of WEBS. Countless tools are available nowadays to develop applications for the Internet. The selection criteria for the technologies used in this work were as follows:

- *Open source*: All technologies used are open source to date, and could be found and downloaded, when applicable, from the Internet.
- *No installation needed*: For web applications, the need for plugins or other software package installation can lead users to frustration, due to their inability to setup the application or distrust of the content of software downloaded from the Internet. To avoid those caveats, all technologies depending on any kind of installation were excluded from this work.
- *Learning curve*: The technologies used should have an acceptable learning curve that would allow a student without previous experience in coding to learn and use them, within the time frame of the development of this thesis.
- *Documentation*: Some open source technologies, although having a friendly learning curve, are not well documented, hindering the learning process. The technologies used should have enough documentation to allow for learning using only the documentation available on line.

The following sub-sections give a further description of the technologies used and their particularities.

a. HTML5

The standard used to present content in webpages is HTML5, which stands for the fifth version of the Hypertext Markup Language (HTML). It is the core technology used to build any web-based application meant to run on a web-browser. Some understanding of the HTML5 language is indispensable for the development of webpages. Due to its popularity, sources from which to learn HTML5 abound on the Internet, making it easy to learn without attending any specific course.

Among the new features added in the fifth version are the canvas element, which is especially important for this thesis. The canvas element was introduced primarily to allow rendering of two-dimensional (2D) graphics and applications on web-browsers, but ended up enabling 3D rendering, in association with WebGL (Anyuru, 2012).

b. JavaScript

JavaScript is a prototype-based scripting language, developed to leverage the capabilities of HTML by allowing the specification of behaviors through programming. All modern web browsers include JavaScript interpreters, and it is used on the overwhelming majority of websites to date (Flanagan, 2011). JavaScript is the language of choice to develop dynamic applications for the web. Due to the relevance that the language has gained in the Internet, since the first release of the language, successive advances have been made to the standard and to the interpreters, making it faster, lighter, and more powerful. Nowadays JavaScript has left behind its scripting-language roots and has become an efficient, general purpose language that supports multiple programming paradigms.

c. Cascading Style Sheets (CSS)

The Cascading Style Sheets (CSS) is a language used to define the appearance and format of webpages written in HTML5. Although not strictly necessary for the

styling of webpages, the use of CSS makes the design of the graphical user interface (GUI) for webpages much easier and richer.

d. WebGL

From all the technologies listed here, WebGL is perhaps the most important regarding the development of a WBS, because it is the standard that makes 3D rendering possible on an HTML5 canvas. WebGL enables hardware-accelerated 3D graphics to be included in a web browser. It is an open standard that can be implemented and used without charge for royalties. It runs natively in the web browsers that offer support for it, without the need for any plugin or installation (Anyuru, 2012).

The first version of the standard was released in 2011 (Khronos Group, 2011), having the second version released in 2013. It is a relatively new technology, which still lacks support from some web browsers. Figure 12 offers a summary table of the support offered to WebGL by the time that this thesis was written. The table shows the support per version of the web browsers. The current versions are outlined in black, and the table also shows a preview of support in the next versions. One can note from the table that the support for mobile devices is currently very low.

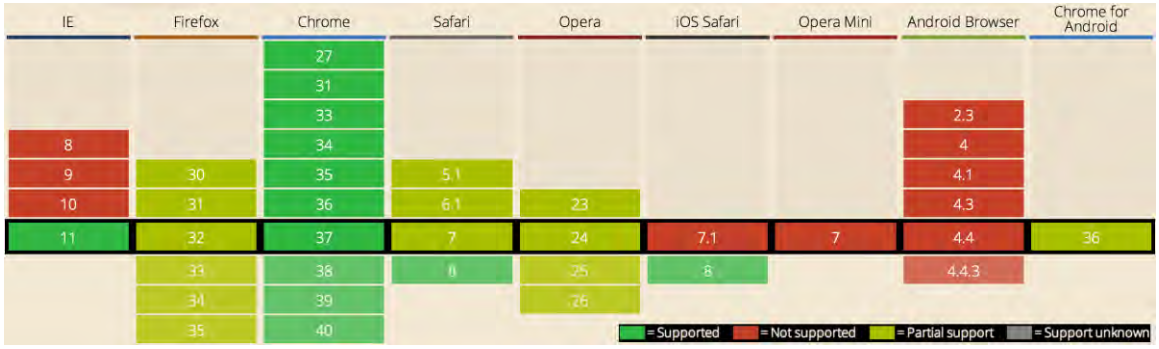

Figure 12. Cross browser support for WebGL as of August 2014 (from Deveria, 2014).

Besides the need for compatibility with the browser, there are additional compatibility issues with the hardware, most frequently with older control processor units (CPUs). Also, some hardware, although natively compatible, comes with WebGL

disabled by the factory settings. The known hardware with this condition is listed in Table 8, based on the "blacklist" maintained by the Khronos Group (2014). Safari is the only modern desktop browser that comes with WebGL disabled by default.

Table 8. List of hardware with WebGL disabled by factory settings.

Browser	**Operating System**	**Hardware**
Mozilla Firefox	Windows older than XP	All
	Windows newer than XP	NVIDIA < 257.21
		ATI/AMD < 10.6
		Intel drivers earlier than September 2010
	Mac OS X < 10.6	All
Google Chrome	All	Intel Mobile 945 Express family of chipsets
		NVDIA GeForce FX Go5200
		ATI FireNV 2400
		Parallels drivers older than version 7
		S3 Trio cards
	Windows	All graphics drivers before 2009
	Windows XP	All ATI/AMD drivers older than version 10.6
		All NVIDIA drivers older than version 257.21
		All Intel drivers older than version 14.42.7.5294
	Mac OS X	ATI Radeon X1900
		NVIDIA GeForce 7300 GT
		All cards have WebGL's initializing disabled
	Linux	ATI/AMD GPUs with proprietary AMD drivers older than version 8.98
		NVIDIA GPUs with proprietary NVIDIA drivers older than version 295
		Multisampling is disabled on Intel IvyBridge cards
		NVIDIA Quadro FX 1500
		WebGL is disabled on the dynamically switching NVIDIA+Intel GPUs
	Android	WebGL is disabled on devices that do not support ARB_robustness or EXT_robustness with context reset notification

The lack of wide cross-browser and cross-platform support is an important issue when considering a technology that could be used to build a WBS. One of the critical

points of web development is that the developer has no control over the user's computer configuration. The applications that fail to reach and be adopted by a wide range of users can be sentenced to oblivion.

Another important aspect is the computational power of the user's machine. Even when the user has all the software and hardware ready to run the 3D application but the computer processor is designed for lighter tasks, it may happen that the application will not run, or it will provide an unsatisfactory user experience.

Even though the current incompatibilities of WebGL may represent a problem for widespread applications, the usefulness of the technology already surpasses its caveats. Furthermore, it may be just a matter of time before WebGL is running without problem in all browsers and platforms, just like JavaScript is running now.

e. JavaScript Libraries

All JavaScript libraries used in this effort are free and distributed under the MIT license. The library that had the most important role in the development was "three.js," which is a JavaScript library and API that automates several routine procedures of WebGL, making it easier to code 3D applications.

The library jQuery was used for help on JavaScript coding. It was used in association with the collection of widgets called "jQuery UI," which offers a variety of user interface elements implemented with CSS in combination with jQuery. The collection of widgets includes buttons, sliders, and different types of menus among other elements valuable for the building of a user interface.

Finally, the Tweenjs library was used to automate the interpolation and use of animations.

f. Blender

Blender is powerful open source 3D modeling software that is distributed under the GNU General Public License (GNU GPL) version two. It provides not only modeling, but also texturing, UV mapping, and animation capabilities, among others. The

3D models and scenes developed in Blender can easily be exported to the JavaScript Object Notation (JSON) format allowing easy integration with the web browser.

g. Gimp

The GNU Image Manipulation Program (GIMP) was the selected program to create and modify most of the images and textures used in this project. It is no-cost image manipulation software distributed under the GNU GPL version three. GIMP offers a powerful and resourceful tool that is well documented and easy to learn.

B. MODELS

This section describes the models built for the implementation of the WEBS prototype. Since none of the technology tools used in this effort were designed to be a game engine, most of the functions provided by these engines needed to be coded from scratch.

1. Periscope Screen

A user who is looking at the eyepiece does not see the periscope itself, only an image that could be seen through the periscope lens. The periscope was implemented as an empty object 3D to which the camera was added in the scene graph. The typical circular cropping of the image of the periscope was implemented using an overlapping canvas layer, in which the information of the display could also be rendered, as shown in Figure 13. The information set provided by the display consists of the level of magnification, stadimetric distance measured, and current true and relative bearing of the periscope.

The periscope object has six degrees of freedom; as such it is possible to rotate around and translate it on three axes. Since in this version of WEBS the user does not need to command the periscope to rise or to be lowered, the only control allowed to the user is the rotation of the periscope object around the vertical axis. The other movements cannot be controlled by the user interaction, which is reserved for the simulation of the rocking of the submarine transmitted to the periscope.

The camera object acts as the periscope lens, and it has only one degree of freedom—it could be rotated around its own horizontal axis, simulating the elevation of the lens. As it is subordinated to the periscope, it will also follow all the periscope's rotation to the left and right.

Figure 13. The periscope screen display.

The alternation of the levels of magnification was simulated in three.js just by altering the camera field of view, and then forcing it to recalculate and update the perspective projection.

One important feature of optical periscopes is the stadimeter. Even though it is generally not used in the ARL mission, this functionality should be simulated to complete the basic framework that allows rapid prototyping of other missions. The periscope stadimeter estimates the distance of an object of known height by measuring the angle between the bottom and the top of the object. To measure the angle, the user moves a mirrored image of the object until the bottom of the mirrored image matches the top of the real image. This effect was simulated simply by rendering the scene image as a texture on a semi-transparent plane. The plane is positioned in front of the camera, and its

elevation is controlled by the user, who acts on the assigned stadimeter control. The elevation of the plane is then converted into an angle, and the distance is calculated and displayed on the screen, as shown in Figure 14.

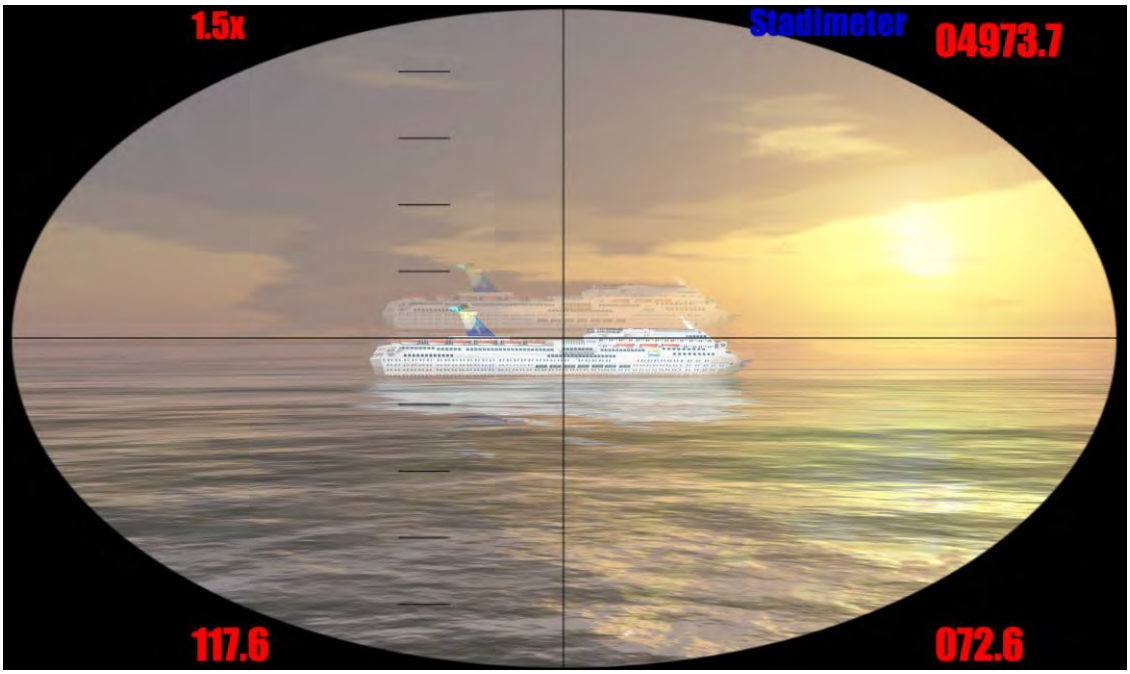

Figure 14. Simulation of the image lagging of a periscope stadimeter.

2. Environment Model

The ocean model was based on a three.js shader for realistic water; it was implemented by Bouny (2014). The model uses reflection, refraction, bump mapping, and normal mapping to simulate the aspect of the water surface on a geometry. Additionally, the vertices of the geometry can have their positions dynamically updated as a function of time, which enables simulation of the effect produced by the waves.

The surrounding sky is simulated with the use of lights and a cubic skybox; a texture needed for a particular situation is applied on that skybox. The skybox images used in this system were shared on the Internet by Reijerse (2006) under a Creative Commons license.

3. Ships and Aircrafts Models

A Java style of object-oriented programming was emulated in JavaScript as proposed by Flanagan (2011) to enable an organized definition of classes, objects, and inheritance. A generic class "Ship" was created to represent most of the attributes and methods common to both ship and aircraft objects. This class defined methods for the animation of the object and helped translate the state of the object into a format common to the naval domain, such as bearing, course, heading, etc. The 3D model was added as an attribute of an object. When a new object is instantiated, the 3D model associated with it is automatically loaded and added to the scene, with the attitude defined in its constructor.

The three.js API allows the use of several formats of 3D models. The models used in this work were in the JSON and OBJ-MTL formats. Most of the 3D models were downloaded originally from the Delta 3D asset library. The library contains some 3D objects in the proprietary format for Autodesk 3DS Max. Those models were converted to the JSON format using a converter written in Python, provided with the three.js API package.

C. GRAPHICAL USER INTERFACE (GUI)

A GUI that was designed to facilitate the user interaction with the application was created using jQuery UI. Most of the GUI elements were used on the main menu, where the user could set the parameters of the simulation before the simulation began running. A snapshot of the main menu aspect is shown in Figure 15.

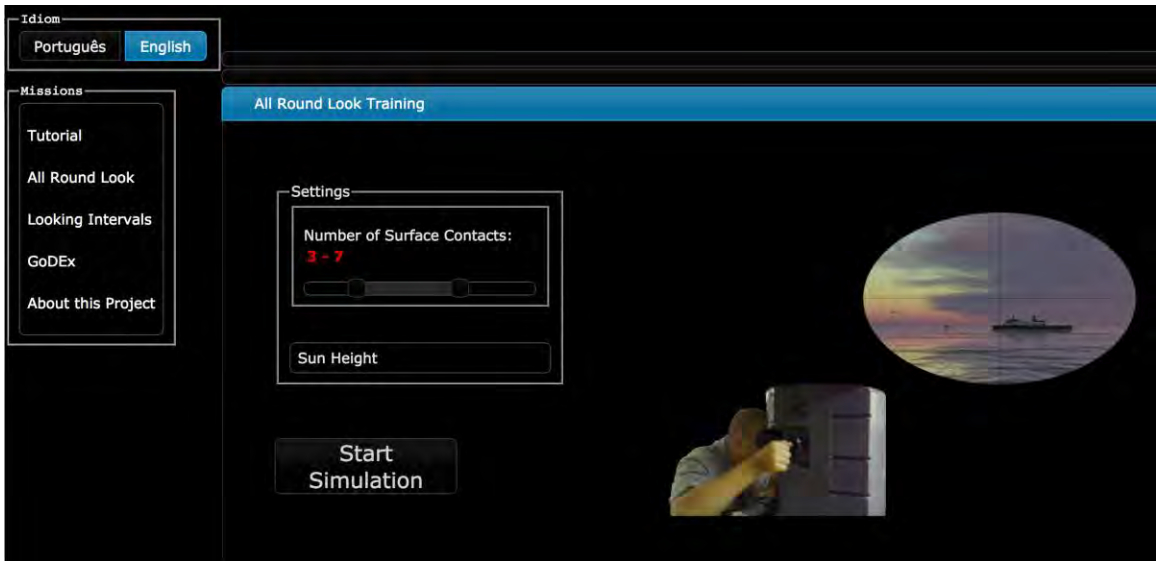

Figure 15. WEBS main menu.

The user can interact with the GUI elements, such as buttons, menu items, etc., by clicking with the mouse, or using the keyboard, by highlighting the element with the "tab" key and then selecting it with "enter" or "return." Affordances were included in the form of tooltips to add extra information for the user on how to interact with the GUI. The tooltip that provides information about an element of the interface is triggered and shown when the user hovers above that element with the mouse cursor without actually selecting it.

A bilingual capability was added to the application. The user could select between English or Brazilian Portuguese in the main menu. Consequently, all the dialogs, menus, and instructions of the interface were presented in the selected idiom. Using the HTML5 local storage capability, once the user selects an idiom, this selection is recorded and automatically set for the next time the user accesses the application.

The main menu offers a selection between several missions available on a sidebar on the left, after which the content of the central portion of the menu gets switched to the configuration panel of that mission. For the ARL training mission, only two settings were made available: the number of contacts and the environment. The user could select the number of contacts either by setting a specific number from one to ten, or by selecting

any range between one and ten. If the user selected a range, a random number of contacts was generated between the minimum and maximum values of that set.

When the user clicks on the button "Start Simulation," the scenario gets loaded and the simulation starts, changing the GUI to the simulation state. Most of the user inputs in the simulation state are made through the keyboard. Table 9 summarizes the controls used for this mission. The objective was to use controls that are as intuitive as possible, and reuse standard keys to avoid user confusion.

Table 9. List of keyboard controls used in the ARL mission.

Key	**Action**
Left and Right arrows	Rotate the periscope
Up and Down arrows	Change the elevation of the lens
	Move the stadimeter image up and down in mode stadimeter
"z"	Toggle through the available magnifications
"s"	Set the object's height for stadimeter calculations
"d"	Toggle stadimeter mode on and off
"Shift"	Increase the turning speed of the periscope
	Toggle the stadimeter from fine to coarse adjusting
"p"	Pause the simulation

If the user wanted to take the stadimeter distance, he could use either the key commands or the mouse wheel, instead of the up and down arrows.

1. Scoring and User Feedback

During the execution of the mission, all MOPs established in Table 7 for the ARL task are evaluated. After all assets are loaded and the simulation is ready to run, the mission begins with the simulation paused. The trainee initially cannot visualize the scene until he or she clicks a button to start running the time. In the initial state, the periscope is pointing to the 000º relative bearing, with the elevation at zero. During the execution time, the application detects the following:

- Total time of execution of the task
- Elevation of the periscope
- Whether or not the 360º were covered
- If the trainee used zoom

After the ARL is finished, the trainee is asked to declare the following data:

- Number of contacts detected
- Classification of contacts
- Estimated bearing on which the contact was detected
- Estimated distance of each contact
- Estimated angle on the bow for each contact

At the end, the trainee is presented with a feedback table, showing his answers and the answers provided by the system (the 'objective' truth).

D. CHAPTER SUMMARY

This chapter discussed the main aspects of the development of the WEBS. The WEBS application was developed with functionalities that can be extended and adapted to implement other missions and PTT.

Knowing the technology used in this effort and its characteristics, we discussed possible limitations of the application. The main limitations existing to date are probably the few hardware and software incompatibilities of WebGL. Applications with 3D rendering for the web could be easily developed with the open-source tools presented; however, the extent of the distribution and the user's experience with the application can be impacted by those same limitations of hardware and programming environments.

VI. USABILITY STUDY

One major objective has been established for the usability study—to provide the answers to the research questions 4 and 5:

Question 4. What are the usability issues of a web-based 3D simulation (efficiency, effectiveness, and user satisfaction with the user interface)?

Question 5. Do WebGL compatible web-browsers have the resources to fully support a web-based 3D simulation?

To address these questions, a modified version of WEBS was used in a usability study that engaged human subjects (users) recruited among the Naval Postgraduate School (NPS) body of students. Because the study involved human subjects, including the collection of information from them, all procedures and documents related to the study had to be reviewed and approved by the Institutional Review Board (IRB) team from NPS prior to execution of the study. The details about the design, execution, and results of this study are discussed in this chapter.

A. DESIGN OF THE EXPERIMENT

A starting set of conditions was established for the study. To ensure that the results would reflect the real issues with web-based applications, WEBS was hosted as a webpage on the Internet; this ensured that the application was subjected to the same advantages and caveats discussed in Chapter III. Also noteworthy is the fact that the participants received only a link along with the recruitment email (full text in Appendix A), and accessed the application using their personal computers. Being that the aim was to address the compatibility issues cited in Chapter V, no restriction was made regarding the machine configuration in the recruitment script.

To preserve a sense of self-learning experience and expose possible usability weaknesses, all instructions on how to execute the study were provided via the application itself—there was no personal contact between the researchers and the participants. The following sections present further details about the elements of this usability study.

1. The Modified Mission

A modified mission was configured to serve the usability study. Because the main objective of the study was not to test the instructional effectiveness of the application but the usability of the user interface, this modified mission was focused on presenting the participants with the functionalities of WEBS and not necessarily on training techniques. The mission presented to the participants consisted of a tutorial about the functionalities of WEBS, followed by an ARL task.

After the user accessed the link provided in the recruitment email, he/she was redirected to a webpage with the survey consent text (full text in Appendix B). The consent briefly described the objectives of the study and how the study would be conducted. In this page, a link was provided to a version of the consent form in a print friendly format, in case the participant wanted to print it for future reference. Clicking on the button entitled "I consent to participate," the participant was redirected to the page with WEBS main menu. This button also triggered a function to save a key in the local storage of the user's browser. Before loading, the main menu webpage would check that key, and if the key was not found, the participant would be redirected to the consent page. Besides the fact that the link to the main menu was not provided, this procedure was added to assure that no one would accidentally have access to the study without having consented to their participation in the study.

After checking for consent, the main menu page would proceed with a series of checks during the loading process; the procedural diagram of the checks is reproduced in Figure 16. The checks aimed to assure the following conditions:

1. The instructions would be presented in the selected language from the very beginning.
2. The window of the user's browser was maximized.
3. The user had a browser and hardware compatible with WebGL.
4. In case the user's browser was not Google Chrome, the user would be advised to use it. This advice was based on the fact that in preliminary tests performed while preparing for the main study, WEBS presented the best performance in the Google Chrome browser.

5. If the user had already done the full tutorial, he or she would be given the option to be redirected to the survey or to execute the tutorial again. This was made to assure that, in case the user accidentally reloads the page after finishing the tutorial, he or she would not be forced to execute the full tutorial mission again.

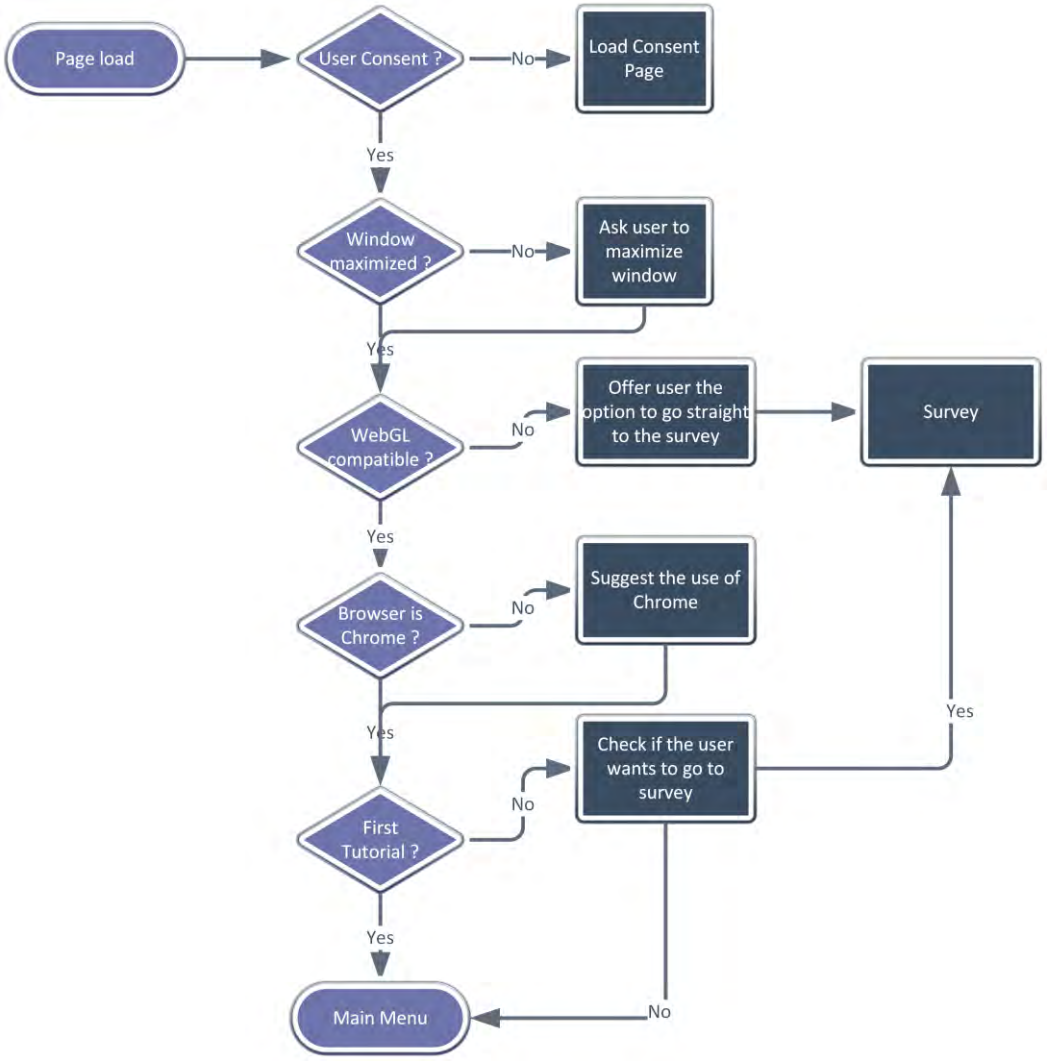

Figure 16. Routine of preload checks performed by WEBS.

Later, after the survey results were analyzed, it was revealed that these checks should have included the instructions to enable WebGL in Safari browsers.

The main menu page was modified from the original version to have only two submenus: 1) the tutorial mission and 2) a menu with further explanation about the project and credits to the third party libraries used in the development. Both submenus had a button to start the tutorial.

During the tutorial, the user was asked to interact with the application using one system control at the time. The goal of the tutorial was to teach the user all system controls, and to prevent the user from getting lost or confused during the session when one control was introduced and some other controls were blocked. In other parts of the tutorial, the application would detect that the user was acting differently than expected for the task and present additional clues to help the learning process.

Figure 18 shows an example of the tutorial task presented to the users during the tutorial session. The successful execution of the tutorial task would automatically trigger the next task. After completion of the tutorial session dedicated to learning the application controls, the user received the final task that consisted of performing an ARL.

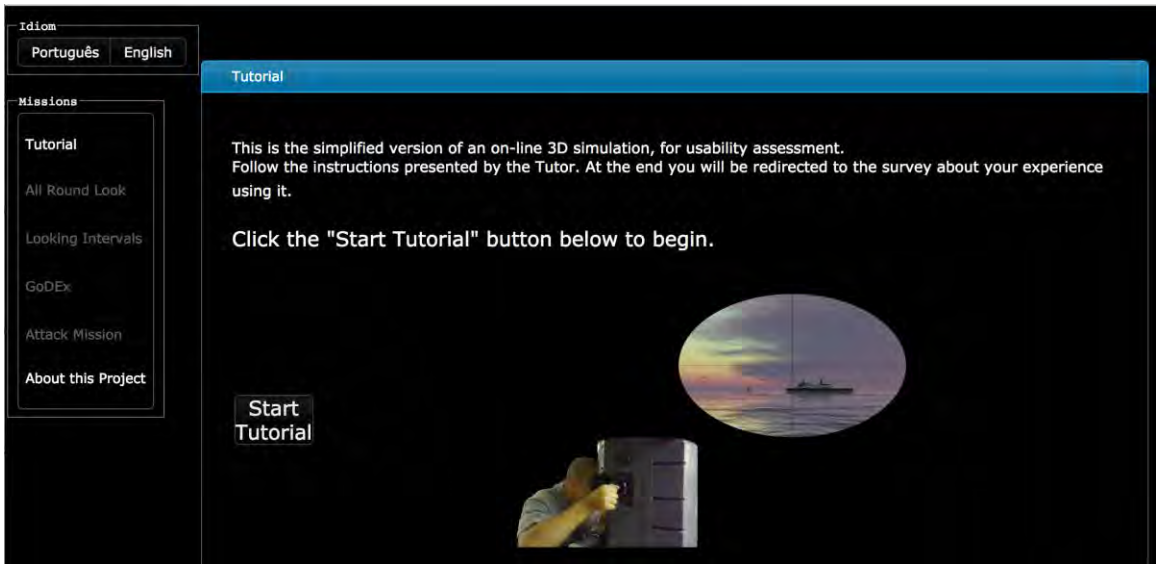

Figure 17. The main menu of the modified mission.

The user would receive a brief instruction about the way an ARL task should be performed and the information that the system would not be assessing his or her performance. The end of the task was triggered either after 30 seconds or when the user covered the 360 degrees with the periscope. After that, a table with all information that could be gathered from the ARL as well as the common errors were shown for the user's information. An example of such a table is shown in Figure 19.

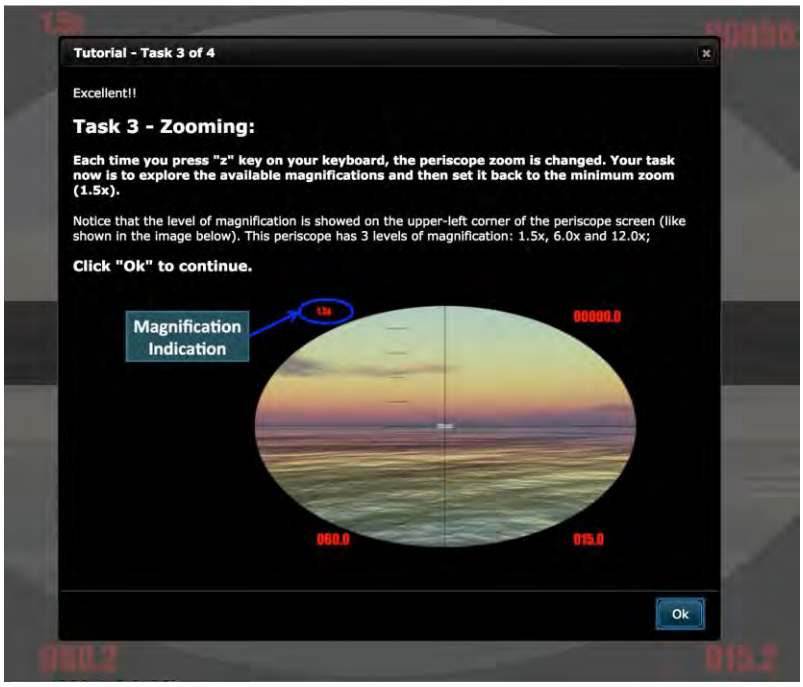

Figure 18. Example of tutorial task.

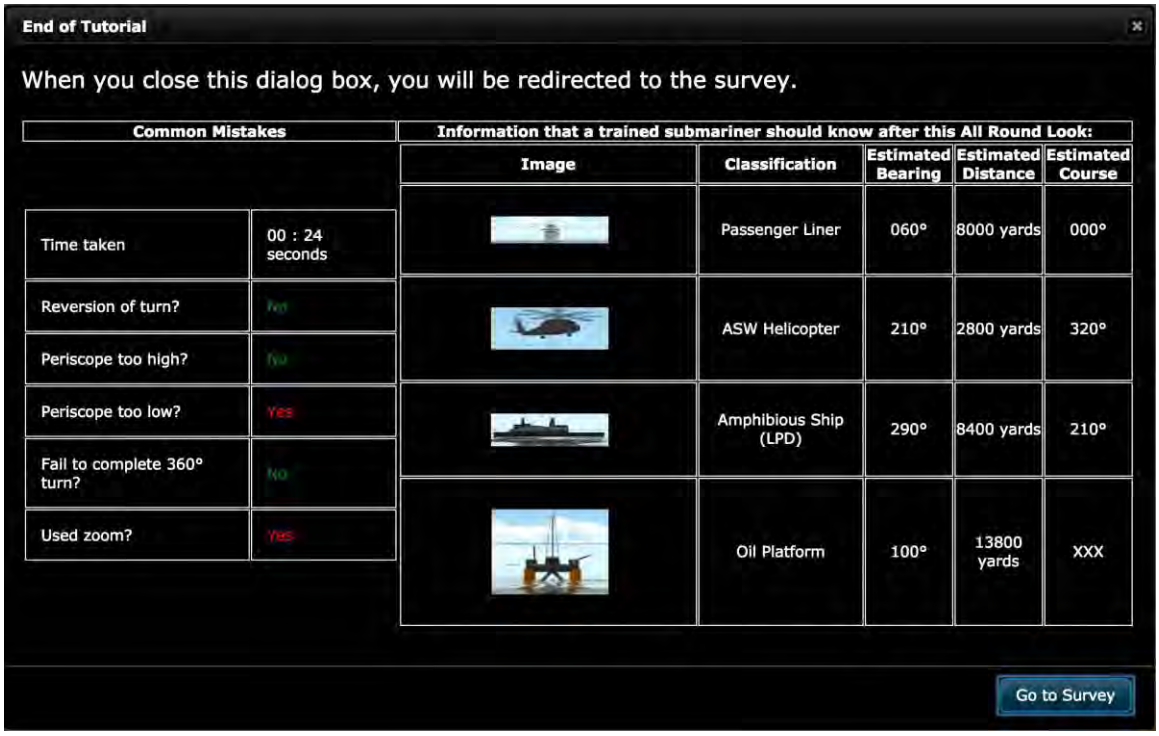

Figure 19. Feedback table presented at the end of ARL task.

After closing the feedback table or clicking on "Go to Survey" button, the user survey would open in a new window or tab of the user's browser.

2. Participant Recruitment

Participation in this study was strictly voluntary and anonymous. The only exclusion criteria applied was that the participants should be adults (over 20 years of age), have higher education, be male or female, and be within the NPS body of students or faculty.

After approval of the process by the IRB, a recruitment email (full text available in Appendix A) was sent to the whole body of students. The survey was answered by a total of 78 participants; only 72 completed all questions in the survey.

3. Post-Session Survey

The survey (available in Appendix C) was created using LimeSurvey, and made available on the Internet. LimeSurvey is an online open source survey tool (Schmitz, 2012); the version used in this study was hosted on the NPS server and made available to NPS students and faculty. The tool complied with all required standards of protection of personal data. The main body of the survey was composed of 50 questions divided into four sections: (1) Demographics, (2) User Experience, (3) Learning Experience, and (4) Comments and Suggestions. No question was made mandatory, so that the participants could skip any question they judged as not applicable. This particular configuration was made mainly to allow the collection of data from participants who could not use WEBS due to some unforeseen technical problems.

The first section, Demographics, was aimed at gathering information about the participants and their habits using the Internet. The following section, User Experience, had questions regarding the experiences the participants just had with WEBS. In the Learning Experience section, the questions focused on the experience and opinions of the participants about learning tools like WBLE and about other simulations. In the last section, Comments and Suggestions, a set of free open-ended questions were made to allow the participants to add comments or suggestions for issues that perhaps were not listed in any other section.

LimeSurvey supports internal logic between questions, which facilitates the assignment of questions relevant to the participant on an individual basis. For example, a participant who had never experienced simulations before would not be asked about his or her previous experience with simulations. Also, the same question could be submitted to two different classes of respondents and achieve individualized results related to each class.

The data collected by the survey tool could be extracted in different formats, such as spreadsheets (.csv or Microsoft Excel), PDF, or SPSS, allowing for easy analysis.

B. RESULTS ANALYSIS

All the responses to the survey are summarized in a graphical form in Appendix G; this section illustrates the analysis of a selected set of responses.

1. Participants' Background

From all the respondents, 12.5% have used a full-scale periscope simulator before. A slightly greater number of participants, 16.67% of them, had previous experience with games featuring periscope simulations. Other types of computer-based simulations (not including the submarine domain) were used by 48.28% of the participants. From the respondents of this survey, only 19.44% were submariners. Among the submariners, 35.71% had less than 3 years of service in submarines. The techniques presented in this thesis are based on procedures taught at BNSS, and common to most conventional (non-nuclear) submarines. The submariners who participated did not necessarily have the same background or are familiar with those techniques. Given the low percentage of submariners, it becomes inappropriate to make general conclusions and associate them with the profession of submariners. Only one of the submariners had experience as an instructor in submarine courses; he had two years' experience in that capacity.

2. Online Habits

A selected set of questions were aimed at collecting the data about the familiarity of the participants with Internet and web-based applications. The results showed that the participants were quite familiar with the use of the Internet and online applications. Only one participant claimed to access the Internet once a week, on average, and the vast majority (98.61%) claimed to access the Internet on a daily basis. All the participants were accustomed to Internet browsing and using email. The third most frequently used web applications were the ones associated with e-commerce (95.83%), followed by multimedia streaming (87.5%), and social networks (73.61%). The attendance in online courses came next with 66.67%, ahead of online games (26.39%). To check if the participants had a different idea about online courses and online training, it was also asked if they had ever done any kind of web-based training before, not giving a definition

of the concept of web-based training. Instead of a discrete answer, this question required an answer using the Likert scale with five levels to capture if the participants felt that they had been enrolled online training previously. The results were higher than for online courses, having those who agreed and those who strongly agreed at the level of 85.71%.

Relevant insights came from the hardware that people used to access the Internet and how they used it. Among the surveyed population, the device of choice to access the Internet was the personal computer. Laptop and desktop users represented 80.55% of the participants who use the Internet. This is important information for all simulations based on WebGL, especially knowing its limited compatibility with mobile devices. Only 5.56% of the interviewed participants preferred tablets, while smartphones were the devices of choice for 13.89% of study participants. It is generally considered that not all tasks can be trained with the same effectiveness on different devices—the acquisition of some types of knowledge and skills are better suited for one type of device, and another type of knowledge and skills is better suited for another type of device. However, when asked what device they would choose to perform a web-based training, 57.14% of the participants chose the laptop, 21.43% preferred a desktop computer, 12.86% the tablet, and only 5.71% of participants chose the smartphone.

Participants were also asked about the devices that they owned for their personal use, excluding those that they currently own but which are destined for the use by another member of the family (for example, tablets being predominantly used by the participant's children). The most commonly owned devices were the laptop (97.22%) and the smartphone (90.28%). Although tablets were not so popular for Internet access, they came in third place with 63.89%. The desktops came next, with only 50%. This is important data for the design of future applications, since the input devices generally differ a bit between desktops and laptops. Most of the laptops do not use a mouse, and instead they offer touchpads. Given this understanding, it would not be a good choice to bind a control of the application strictly to the mouse wheel, for example.

3. User Experience with WEBS

Most questions about the user experience with WEBS were made using the Likert scale. To facilitate the visualization of the results, the graph in Figure 20 was created with the mean values for each question, considering only the valid answers. The Likert values correspondence range from 1 for a "strongly disagree" answer to 5 for a "strongly agree" answer. The graph provides a good idea about the average response; however, as it is based on mean values, important trends could be masked. A more complete understanding is achieved by checking the distribution plot and the standard deviation for each question. The complete set of responses can be seen in Appendix G.

Figure 20. Summary of Likert scale mean values for the user experience with WEBS.

The overall picture gives the idea that the elements of the interface were on a satisfactory level, suggesting also that there was room for improvement. A slightly lower satisfaction was expressed regarding the feeling of self-efficacy of the participants—this was the question that inquired about their ability to complete the task. The evaluation of open-ended questions suggests that this may have been caused by the fact that, although the application did not evaluate the participants, it offered feedback about what the performance standards of a trained individual should be. In some comments, the participants would say that they felt that if they had trained a little bit more they would have achieved a higher level of performance. Another aspect to be revised is the explanation about the purpose of the WBS. The results show that about one-third (31.94%) of participants was in doubt or neutral about the purpose of the simulation.

To get some idea about the realism of the simulation, only the submariners were asked about the extent to which WEBS reminded them of their experience with a real periscope. The average Likert scale renders a fair result of 3.1, suggesting that when it came to simulated level of realism, there was a lot of room for improvement. Again, it is important to be reminded that the small group of submariners surveyed in this study may have been composed of participants with a diverse background, such as individuals who have been used to different types of equipment. In open-ended comments, three submariners expressed their concern about the fact that the controls were too different from what they were used to. Another participant commented about his or her concern that the bio-mechanical part of the task could not be reproduced on a personal computer.

Finally, although most of the participants claimed not to have had major technical difficulties, like image freezing, flickering, etc., a great number of them (40.28%) felt that some technical difficulty influenced negatively their experience with the application, while 30.56% were neutral on this point.

4. The Gap Classroom – Simulator – Operational Environment

One of the research issues addressed by this thesis was the assumption of an existing gap between the theoretical classroom teaching and the hands-on training on simulators or actual operational environments (equipment). The respondents with

experience in training with simulators were asked about the way they felt regarding their preparedness before and after the training session on a full-scale simulator. Three main aspects were addressed about how they felt: (1) if they felt prepared to begin the simulator training; (2) if they had a clear understanding of the tasks that would be performed at the simulator facility; and (3) if the amount of training on the simulator that they used was enough to prepare them for the operational environment. The summary of mean Likert values for these responses can be seen in Figure 21.

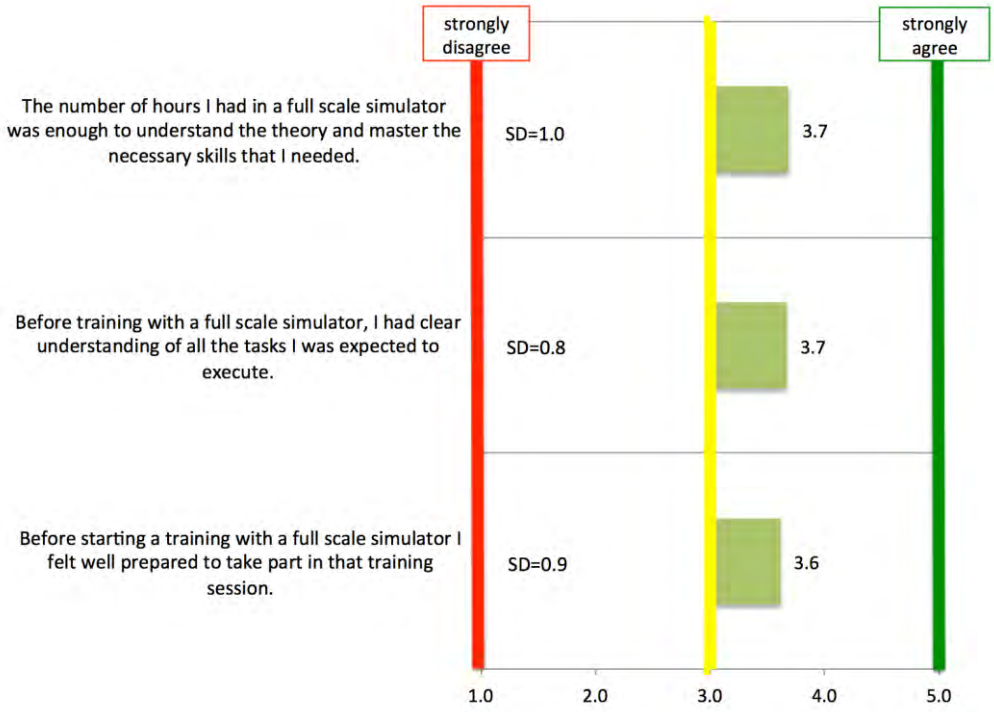

Figure 21. Summary of Likert scale mean values for the user self-reported preparedness regarding simulator training.

Considering the mean values in those questions, the results give the idea that there is a little gap in training, either before or after attending simulator facilities at military training centers. However, once again we need to understand that the mean values can be misleading. Considering only the respondents who marked less than or equal to three, (they were neutral or they disagreed with the statement) the following could be concluded:

- For the statement that the amount of training in simulators was enough to prepare them for the real operational environment, 34.3% of the participants answered that they disagreed or were neutral.
- For the statement that before beginning the training the trainees had a complete understanding of the tasks that would be performed, 36.1% of the participants answered that they disagreed or were neutral.
- For the statement that they felt well prepared to take part in simulator trainings, 41.7% of the participants answered that they disagreed or were neutral.

These results show that, although not unanimous, there is an unfulfilled gap in training for some people. The fact that this gap is not generalized, reinforces the potential for the use of WBS made available to the trainees on a voluntary basis; the trainees who felt a need for more training between the classroom and training simulators, and between the training on simulators and the real operational environment could opt to fill that need by using the type of training tools like WBS.

5. Acceptance of Web-Based Training

A set of questions was focused on the willingness of the participants to voluntarily participate in online training. Overall the results show that the participants had a positive attitude towards web-based training.

The participants with experience on training simulators were asked if they would use a WBS to prepare for an upcoming training on the full-scale simulator, and 83.78% of them agreed that they would. The only submariner with experience as an instructor agreed that this tool would be valuable as an instructional help. When asked about the place of preference where they would perform web-based training, 62.86% responded that they would do it at home, while 35.71% would prefer doing it at work. As for the point in time when they would do the training with a WBS, most people (58.57%) had opinion that it would be useful both before and after the training with the full-scale simulator; a total of 35.71% of participants found it to be more useful before in-base training with simulators, and 2.86% found it not to be useful at all.

Figure 22 offers a summary of the mean results of questions related to participants' willingness to use and their acceptance of web-based training.

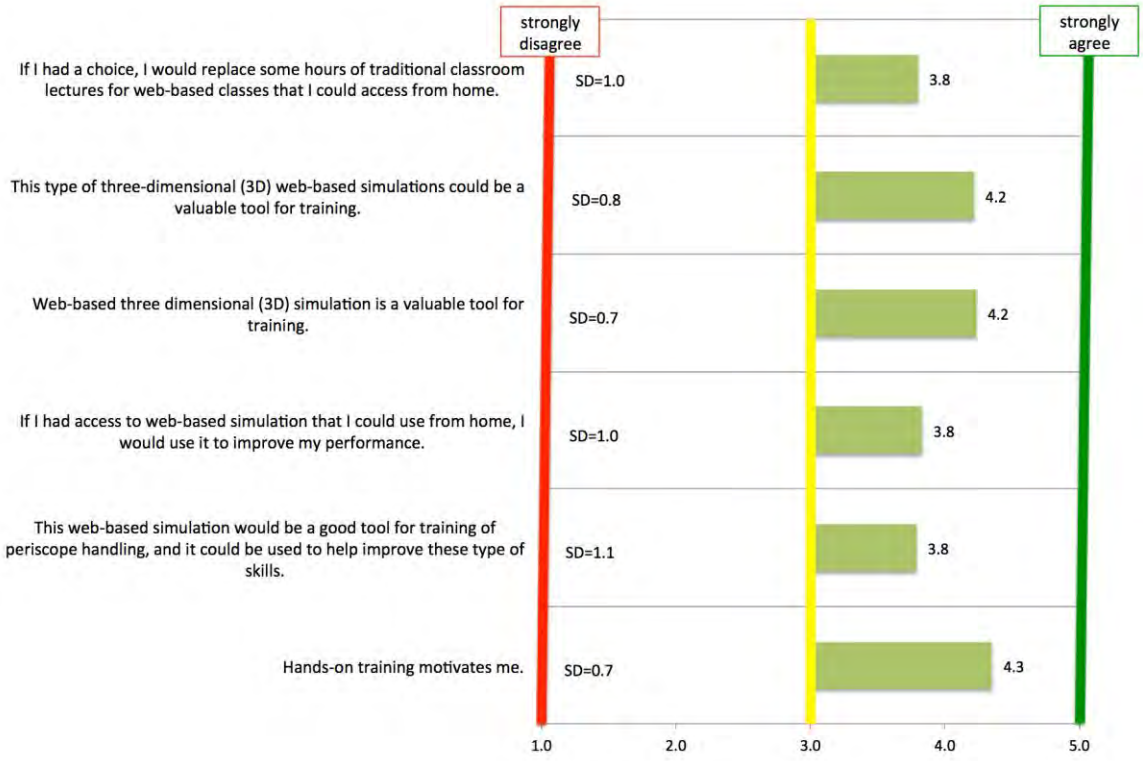

Figure 22. Summary of Likert scale mean values for the user's propensity to adopt web-based trainings.

The majority of the participants (90%) feel motivated by hands-on training. Most people (71.43%) agreed that they would voluntarily replace a part of their classroom lecture time with the web-based content that could be accessed from home. Most participants (88.57%) also had the opinion that WBS and applications like WEBS represented a valuable tool for training. More specifically, participants suggested that WEBS would be a valuable tool for training of periscope handling (the mean value of 3.8). The participants also showed a willingness to voluntarily use a WBS from home to improve their performances with the same mean.

6. Open-Ended Questions

There were three open-ended questions, inviting the participants to volunteer any additional comments, concerns, or suggestions for improvement that they might have. Adding up the responses for all three questions, a total of 31 participants provided their comments. From those, 14 reported technical difficulties that either impeded or hampered the execution of the tasks proposed. However, some of these limitations could have been avoided by adding the instructions about how to enable WebGL in the Safari browser, as the application failed to do it (the same was also reported by participants who were Safari users).

The second more frequently cited concern, mostly provided by the submariners and pilots, was related to the lack of simulation of mechanical movements of the body, and the difference between the human-machine interfaces on personal computers compared to the real environment. This concern reinforced the suitability of a PTT approach for WBS, focusing only on those tasks not strictly linked to the operation of equipment and mechanical skills. In addition, it stresses the need for providing plenty of information to the users, to avoid them being unaware of the objectives of the application.

Less frequent but still noteworthy were the suggestions to improve the color patterns of the simulation, using different keys to make the interface more intuitive, and improving the realism by adding more environmental cues. Also, four participants expressed their concerns about the clarity of instructions provided in the application, suggesting that further improvement should be made to make them clear.

7. General Analysis

The analysis of the results was positive regarding the usefulness and suitability of WBS for distance learning and training. The background of the population that participated in the study revealed high familiarity with web-based applications and a high willingness for the adoption of this type of training on a voluntary basis. The results also contribute towards the assumption that there exists an instructional gap between the classroom teaching and the training on simulators, at least for a portion of the trainees. The use of WBS could become a valuable tool in reducing this gap, ensuring that the

trainees went to training centers with a higher understanding and mastery of the basic skills.

The technical difficulties related to the technology employed for this application were also made evident. Although a large majority of the participants was able to execute the application, there was still a great number of participants who were not able to take total advantage of simulations built using this technology. It was also made evident that, although well accepted, the application has room for several improvements before being finally distributed for real training.

VII. CONCLUSIONS AND FUTURE WORK

A. CONCLUSIONS

Computer-based simulations have been used successfully to aid the training of complex skills and dangerous tasks common in military professions. Their use, however, requires the trainees to attend training sessions in specific locations inside a training facility that typically has limited availability. Very specifically, for the training of periscope depth safety rules for the submariners, using the "eyes-only" style common to conventional submarines, the trainees need to master several concepts and skills before their very first contact with the periscope simulator. The theoretical concepts are taught in the classroom environment, but the mastery of skills demands individual effort and takes time not available during the lecture portion of a course. Frequently the trainees use part of their training time in the simulator to correct and master those basic skills, wasting precious time that could be used for more advanced training.

Web-based simulations can potentially be used to diminish this gap between theory and practice, providing an instructional environment that the trainees can access from home and adapt to their time and convenience. Today, advances in web-based technology allow the delivery of simulations that include complex virtual environments without the need for installation of plugins or the use of proprietary software.

For this thesis, a prototype of a web-based periscope simulation was developed to allow the testing of this concept. A usability study was performed in which the volunteers accessed the online prototype, accomplished a tutorial session and a simple mission, then responded to an online survey, and left their impressions about the prototype and this training modality. The results showed that people were receptive to web-based training; most of the military with experience of training with simulators were willing to use a part-task training web-based simulation to improve their performance.

Technical issues were also evidenced. Most of the participants were able to use the application as intended, but some participants experienced difficulties due to incompatibility of their hardware or software with the technologies used in WBS, or due

to the lack of computational power. This study confirmed our belief that web-based simulations for training should not be extremely dependent on the hardware configuration; they should not lose the most remarkable advantage of web-based applications: the ability to deliver the same content on different platforms without the need for software installation, and to deliver this content to the user virtually anywhere and anytime. But web-based technology is constantly and rapidly evolving. Each day more computational power is available at the user's home. This leads to the conclusion that the web-based simulations represent valuable and viable tools for improving future training, making a link between the training on the full-scale simulators and the classroom environment, as well as being useful for the refreshing of skills for those professionals who are already trained.

B. FUTURE WORK

The prototype application built for this thesis had the usability of the user interface as its objective. Further development of the application should include:

- Creation of additional missions to enable training of other important skills.
- Development of simulations for part-task training on other subjects in the submarine domain not related to the periscope.
- Creation of a library of relevant 3D models, more realistic and optimized for use in the Internet.
- Implementation of an intelligent tutoring system to leverage the self-paced learning.
- Improvements in the GUI and in the usability of the application.
- Optimization of the code to improve the user experience while demanding fewer hardware resources.
- Development of better graphical effects to improve the level of realism.
- Development of a software framework, along the lines of a game engine, to ease future development of simulations.

Beyond further development of the application, a deeper usability study should be conducted with a complete web-based simulation aimed only at the final target population (that is, 'end users'). Also extremely important is the research focused on training effectiveness and transfer of skills using this type of training tool.

The submarine operations domain was the basis for this thesis, but research should also be done to extend this concept to other domains.

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APPENDIX A. SURVEY RECRUITMENT SCRIPT

To All NPS Students,

You are invited to participate in research study that will help us test the elements of a Web-Based Submarine Periscope Simulator; you will be able to run it on your own computer using a web browser of your choice.

You will go through following steps: (1) do a simple 5 minute-long training session, (2) execute the main task, (3) answer a short survey about your experience.

Your participation is voluntary, anonymous, and **will only take about 15 minutes**. **No** personal data are collected.

Please click here to participate in the study. If the link does not work, please copy and paste this link into your browser: http://www.simulasub.org

If you have questions regarding the research, contact **Principal Investigator**, Dr. Amela Sadagic, 831–656-3819, asadagic@nps.edu. If you have any questions regarding your rights as a research subject, please contact the Naval Postgraduate School **IRB Chair**, Dr. Larry Shattuck, 831–656-2473, lgshattu@nps.edu.

We recognize how busy you are. **Your participation supports the effort of a thesis student, and we appreciate your willingness to assist** in this short study.

If you have any questions, please do not hesitate to contact us.

Sincerely,

Amela Sadagic, Ph.D.
Research Associate Professor
MOVES Institute
Naval Postgraduate School

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APPENDIX B. SURVEY CONSENT

Naval Postgraduate School
Consent to Participate in Anonymous Survey

You are invited to participate in a research study entitled "User Acceptance Survey of Web-Based Submarine Periscope Simulator." The purpose of this research is to help in evaluating the potential acceptance of a web-based periscope simulator for submarine officers basic training. Your participation will be a valuable source of information to improve future research in this field.

The experiment consists of completing the online tutorial about how to use the simulator, and then completing the first mission, an all-around search using the periscope simulator. The completion of these two tasks will take about 10 minutes. After this you will be redirected to a survey about your experience with the web-based simulation. This survey should take about five minutes to complete. Your participation is voluntary. There is no direct benefit to you for participating. If you participate, you are free to skip any questions or stop participating at anytime without penalty. Your responses are anonymous. Results of the survey will be used responsibly and protected against release to unauthorized persons. All data collected will be safeguarded on the NPS secure server; however, there is a minor risk that data collected could be mismanaged.

If you have questions regarding the research, or experience any injury, contact Principal Investigator, Dr. Amela Sadagic, asadagic@nps.edu. If you have any questions regarding your rights as a research subject, please contact the Naval Postgraduate School IRB Chair, Dr. Larry Shattuck, 831–656-2473, lgshattu@nps.edu.

☐ I consent to participate.

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APPENDIX C. SURVEY QUESTIONS

Besides the whole set of questions, the logic applied is also reproduced in this appendix. Some questions were repeated, so that, using the logic, they could be targeted at different respondents.

Usability assessment of the Web-Based Submarine Periscope Simulator

This survey aims to assess the usability of a web-based tridimensional simulation for training.

There are 50 questions in this survey

Demographics

Are you a submarine officer?

Please choose **only one** of the following:

- ○ Yes
- ○ No

How many years of experience in the submarine service?

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '1 [D1]' (Are you a submarine officer?)

Please choose **all** that apply:

- ☐ Less than 1 year
- ☐ Between 1 and 3 years
- ☐ Between 3 and 6 years
- ☐ More than 6 years

Have you ever used a full scale periscope simulator for your training?

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '1 [D1]' (Are you a submarine officer?)

Please choose **only one** of the following:

- ○ Yes
- ○ No

How much preparation (in hours) do you typically do before starting a training session with a full scale simulator?

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '3 [D3]' (Have you ever used a full scale periscope simulator for your training?)

Only numbers may be entered in this field.

Please write your answer here:

Please answer an estimated amount of hours.

"Preparation" means that you had to study and/or train by yourself before going to the simulator session.

If you had access to web-based (on-line) simulation, would you use it to help you prepare for your possible upcoming training on the full scale simulator in base?

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '3 [D3]' (Have you ever used a full scale periscope simulator for your training?)

Please choose **only one** of the following:

- ○ Yes
- ○ No

Have you ever been an instructor for submarine courses?

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '1 [D1]' (Are you a submarine officer?)

Please choose **only one** of the following:

- ○ Yes
- ○ No

For how many years have you been an instructor?

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '6 [D6]' (Have you ever been an instructor for submarine courses?)

Only numbers may be entered in this field.

Please write your answer here:

Would you use an online simulation like this to execute a training session as an instructor?

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '6 [D6]' (Have you ever been an instructor for submarine courses?)

Please choose **only one** of the following:

- ○ Yes
- ○ No

Have you ever played any submarine game with a periscope simulation?

Please choose **only one** of the following:

- ○ Yes
- ○ No

Have you ever used a computer-supported simulation for training? (examples: flight simulation or training simulations for ground operations).

Only answer this question if the following conditions are met:
Answer was 'No' at question '1 [D1]' (Are you a submarine officer?)

Please choose **only one** of the following:

- ○ Yes
- ○ No

How much preparation do you typically do before starting a training session with those simulations?

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '10 [D10]' (Have you ever used a computer-supported simulation for training? (examples: flight simulation or training simulations for ground operations).)

Only numbers may be entered in this field.

Please write your answer here:

Please answer an estimated amount of hours.

"Preparation" means that you had to study and/or train by yourself before going to the simulator session.

If you had access to web-based (on-line) simulation, would you use it to help you prepare for your possible upcoming training on the full scale simulator?

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '10 [D10]' (Have you ever used a computer-supported simulation for training? (examples: flight simulation or training simulations for ground operations).)

Please choose **only one** of the following:

- ○ Yes
- ○ No

Select all applications that you use on regular basis in the Internet (select all that apply):

Please choose **all** that apply:

- ☐ Browse the network (use web browser)
- ☐ On-line courses or distance learning modules
- ☐ On-line shopping, e-commerce or e-banking
- ☐ E-mail
- ☐ Multimedia streaming (online movies, music, etc.)
- ☐ Social networks
- ☐ Online games
- ☐ I participate in wikis and web forums
- ☐ I maintain a Blog
- ☐ I maintain a website
- ☐ Other:

With what frequency do you access internet for any application mentioned in the previous question?

Please choose **only one** of the following:

- ○ Daily
- ○ Weekly
- ○ Monthly
- ○ I rarely use the Internet

What is the device you use the most to access the Internet?

Please choose **only one** of the following:

- ○ Desktop computer
- ○ Laptop computer
- ○ Tablet
- ○ Smartphone
- ○ Game console
- ○ Other

Mark below all devices that you own for your personal use:

Please choose **all** that apply:

- ☐ Desktop computer
- ☐ Laptop computer
- ☐ Tablet
- ☐ Smartphone
- ☐ Game console
- ☐ Other:

Mark only those that are for your own use.

User Experience

About your experience with the web-based simulation.

The web-based simulation provided enough guidance – I was able to use it without additional help

Please choose **only one** of the following:

- ○ Strongly disagree
- ○ Disagree
- ○ Neither agree nor disagree
- ○ Agree
- ○ Strongly Agree

The quality of graphics used in web-based simulation was good.

Please choose **only one** of the following:

- ○ Strongly disagree
- ○ Disagree
- ○ Neither agree nor disagree
- ○ Agree
- ○ Strongly Agree

The textual information and numbers were easy to read and provided necessary information to accomplish the task.

Please choose **only one** of the following:

- ○ Strongly disagree
- ○ Disagree
- ○ Neither agree nor disagree
- ○ Agree
- ○ Strongly Agree

The controls were easy to use (zooming in/out, moving left/right and up/down, etc.).

Please choose **only one** of the following:

- ○ Strongly disagree
- ○ Disagree
- ○ Neither agree nor disagree
- ○ Agree
- ○ Strongly Agree

The use of controls was intuitive.

Please choose **only one** of the following:

- ○ Strongly disagree
- ○ Disagree
- ○ Neither agree nor disagree
- ○ Agree
- ○ Strongly Agree

The buttons (elements of user interface) were of appropriate size.

Please choose **only one** of the following:

- ○ Strongly disagree
- ○ Disagree
- ○ Neither agree nor disagree
- ○ Agree
- ○ Strongly Agree

The choice of colors in user interface made the text, numbers and other instructions easy to read.

Please choose **only one** of the following:

- ○ Strongly disagree
- ○ Disagree
- ○ Neither agree nor disagree
- ○ Agree
- ○ Strongly Agree

The meaning of menu items was clear.

Please choose **only one** of the following:

- ○ Strongly disagree
- ○ Disagree
- ○ Neither agree nor disagree
- ○ Agree
- ○ Strongly Agree

The purpose of this web-based simulation was clear.

Please choose **only one** of the following:

- ○ Strongly disagree
- ○ Disagree
- ○ Neither agree nor disagree
- ○ Agree
- ○ Strongly Agree

I was able to complete the task (execute the mission) very efficiently.

Please choose **only one** of the following:

- ○ Strongly disagree
- ○ Disagree
- ○ Neither agree nor disagree
- ○ Agree
- ○ Strongly Agree

This type of three-dimensional (3D) web-based simulations could be a valuable tool for training.

Please choose **only one** of the following:

- ○ Strongly disagree
- ○ Disagree
- ○ Neither agree nor disagree
- ○ Agree
- ○ Strongly Agree

This web-based simulation reminded of my experience in using a real periscope.

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '1 [D1]' (Are you a submarine officer?)

Please choose **only one** of the following:

- ○ Strongly disagree
- ○ Disagree
- ○ Neither agree nor disagree
- ○ Agree
- ○ Strongly Agree

I did not experience any technical difficulties with this web-based simulation (such as: image was freezing, flickering, being too slow, etc.)

Please choose **only one** of the following:

- ○ Strongly disagree
- ○ Disagree
- ○ Neither agree nor disagree
- ○ Agree
- ○ Strongly Agree

There were technical difficulties, but they did not influence negatively the use of this web-based simulation.

Please choose **only one** of the following:

- ○ Strongly disagree
- ○ Disagree
- ○ Neither agree nor disagree
- ○ Agree
- ○ Strongly Agree

This web-based simulation would be a good tool for training of periscope handling, and it could be used to help improve these type of skills.

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '1 [D1]' (Are you a submarine officer?)

Please choose **only one** of the following:

- ○ Strongly disagree
- ○ Disagree
- ○ Neither agree nor disagree
- ○ Agree
- ○ Strongly Agree

Do you have any concern about the use of this product?

Please choose **only one** of the following:

- ○ Yes
- ○ No

What are they?

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '32 [U16]' (Do you have any concern about the use of this product?)

Please write your answer here:

Learning Experience

About the way you learn.

Hands-on training motivates me.

Please choose **only one** of the following:

- ○ Strongly disagree
- ○ Disagree
- ○ Neither agree nor disagree
- ○ Agree
- ○ Strongly Agree

In my past experience, before I would start training with a full scale simulator I felt well prepared to take part in that training session.

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '3 [D3]' (Have you ever used a full scale periscope simulator for your training?)

Please choose **only one** of the following:

- ○ Strongly disagree
- ○ Disagree
- ○ Neither agree nor disagree
- ○ Agree
- ○ Strongly Agree

In my past experience, before I would start training with a full scale simulator I felt well prepared to take part in that training session.

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '10 [D10]' (Have you ever used a computer-supported simulation for training? (examples: flight simulation or training simulations for ground operations).)

Please choose **only one** of the following:

- ○ Strongly disagree
- ○ Disagree
- ○ Neither agree nor disagree
- ○ Agree
- ○ Strongly Agree

In my past experience, before I would start training with a full scale simulator, I had clear understanding of all the tasks I was expected to execute.

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '3 [D3]' (Have you ever used a full scale periscope simulator for your training?)

Please choose **only one** of the following:

- ○ Strongly disagree
- ○ Disagree
- ○ Neither agree nor disagree
- ○ Agree
- ○ Strongly Agree

In my past experience, before I would start training with a full scale simulator, I had clear understanding of all the tasks I was expected to execute.

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '10 [D10]' (Have you ever used a computer-supported simulation for training? (examples: flight simulation or training simulations for ground operations).)

Please choose **only one** of the following:

- ○ Strongly disagree
- ○ Disagree
- ○ Neither agree nor disagree
- ○ Agree
- ○ Strongly Agree

The number of hours I had in a full scale simulator was enough to understand the theory and master the necessary skills I needed before going to the related operational environment.

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '3 [D3]' (Have you ever used a full scale periscope simulator for your training?)

Please choose **only one** of the following:

- ○ Strongly disagree
- ○ Disagree
- ○ Neither agree nor disagree
- ○ Agree
- ○ Strongly Agree

The number of hours I had in a full scale simulator was enough to understand the theory and master the necessary skills I needed before going to the related operational environment.

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '10 [D10]' (Have you ever used a computer-supported simulation for training? (examples: flight simulation or training simulations for ground operations).)

Please choose **only one** of the following:

- ○ Strongly disagree
- ○ Disagree
- ○ Neither agree nor disagree
- ○ Agree
- ○ Strongly Agree

If I had access to web-based simulation that I could use from home, I would use it to improve my performance.

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '3 [D3]' (Have you ever used a full scale periscope simulator for your training?)

Please choose **only one** of the following:

- ○ Strongly disagree
- ○ Disagree
- ○ Neither agree nor disagree
- ○ Agree
- ○ Strongly Agree

If I had access to web-based simulation that I could use from home, I would use it to improve my performance.

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '10 [D10]' (Have you ever used a computer-supported simulation for training? (examples: flight simulation or training simulations for ground operations).)

Please choose **only one** of the following:

- ○ Strongly disagree
- ○ Disagree
- ○ Neither agree nor disagree
- ○ Agree
- ○ Strongly Agree

Web-based three dimensional (3D) simulation is a valuable tool for training.

Please choose **only one** of the following:

- ○ Strongly disagree
- ○ Disagree
- ○ Neither agree nor disagree
- ○ Agree
- ○ Strongly Agree

If I had a choice, I would replace some hours of traditional classroom lectures for web-based classes that I could access from home.

Please choose **only one** of the following:

- ○ Strongly disagree
- ○ Disagree
- ○ Neither agree nor disagree
- ○ Agree
- ○ Strongly Agree

Have you ever done any kind of web-based training before?

Please choose **only one** of the following:

- ○ Strongly disagree
- ○ Disagree
- ○ Neither agree nor disagree
- ○ Agree
- ○ Strongly Agree

If some web-based training is found equally effective on all those devices, what kind of device would you prefer to use for your web-based training in the future?

Please choose **only one** of the following:

- ○ Desktop computer
- ○ Laptop computer
- ○ Tablet
- ○ Smartphone
- ○ Other

Regarding web-based (online) training, I would prefer doing it:

Please choose **only one** of the following:

- ○ At home
- ○ At work

Suggestions and Opinions

When do you think a web-based simulation would be more useful as a training tool?

Please choose **only one** of the following:

- ○ Before using a full scale simulator, to help better visualize and understand the theory.
- ○ After using a full scale simulator, to help retain knowledge and skills.
- ○ Both before and after training with a full scale simulator.
- ○ I do not think it would be useful at all.
- ○ Other

Do you have any suggestion on how to improve the web-based simulation as a training tool?

Please write your answer here:

Provide any comment about your experience with the web-based simulation.

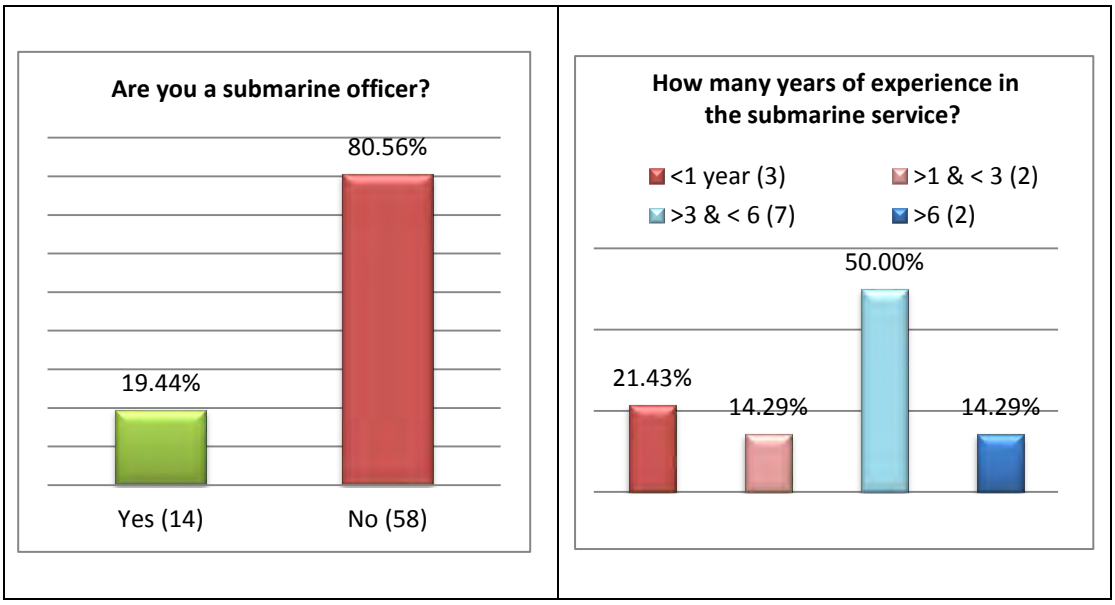
Please write your answer here:

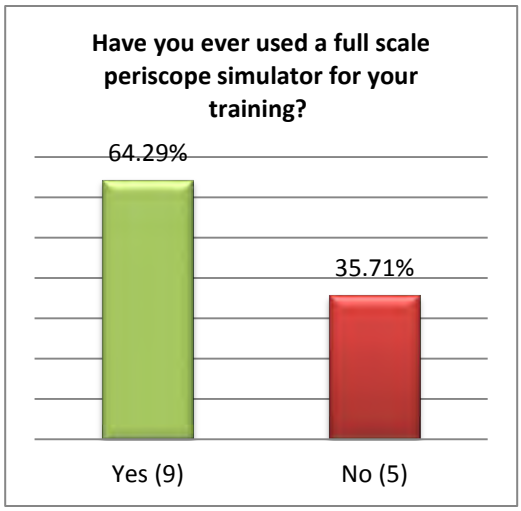
APPENDIX D. SURVEY RESULTS

In this appendix the responses to the survey are summarized. In the graphs, the numbers in parenthesis report the quantity of people who selected that option. The questions that used the Likert scale have the following options represented in the graphics in a numeric format:

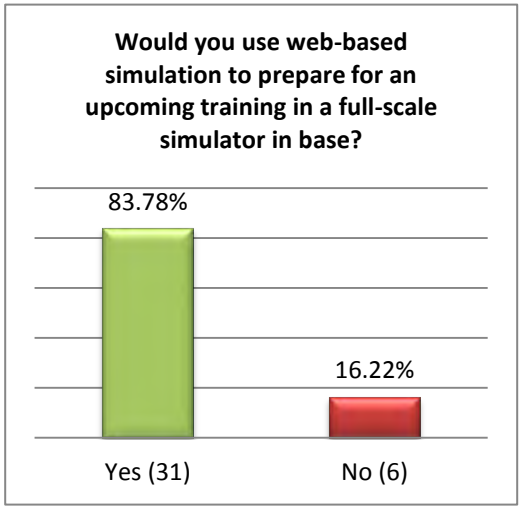
1. Strongly disagree
2. Disagree
3. Neither agree nor disagree
4. Agree
5. Strongly agree

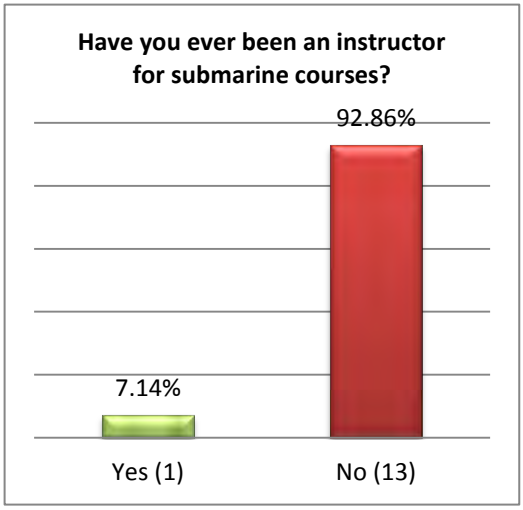
Table 10. Summary charts of survey results.



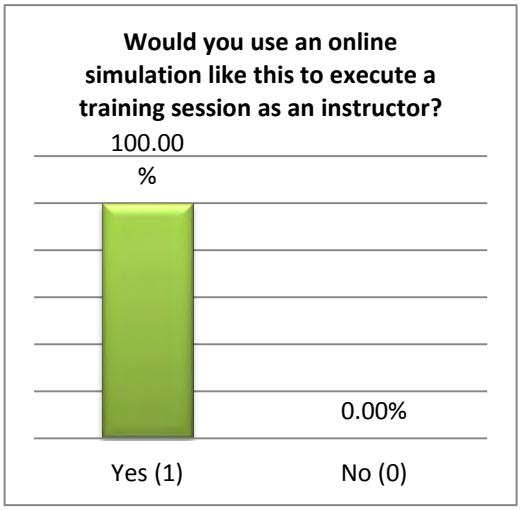


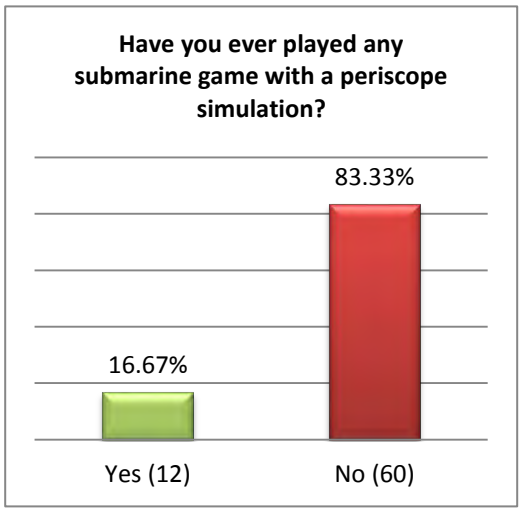
How much preparation (in hours) do you typically do before starting a training session with a full scale simulator?	
Count	9
Sum	4
Standard deviation	0.5
Average	0.44
Minimum	0
1st quartile (Q1)	0
2nd quartile (Median)	0
3rd quartile (Q3)	1
Maximum	1

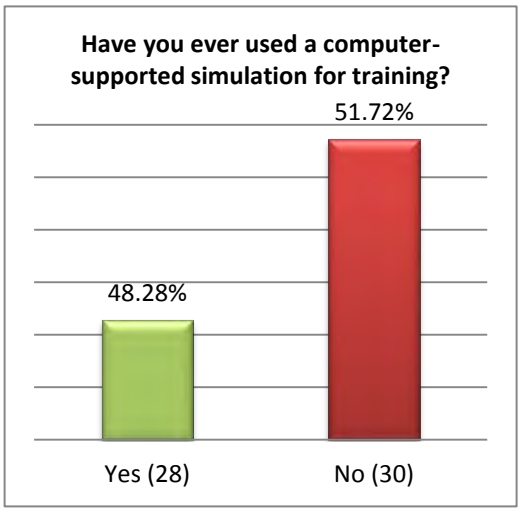




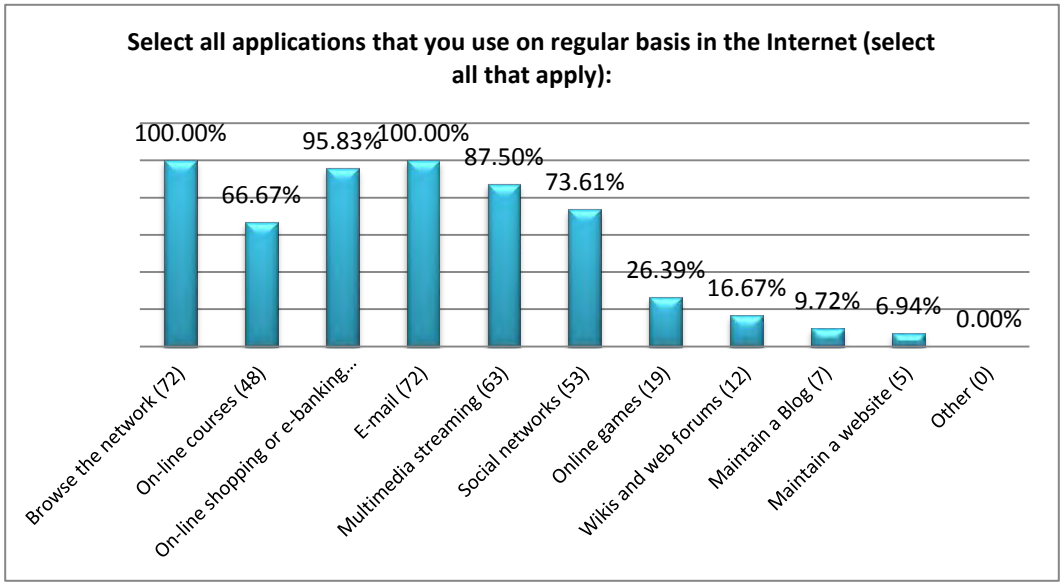
For how many years have you been an instructor?	
Count	1
Sum	2
Standard deviation	0
Average	2
Minimum	2
Maximum	2

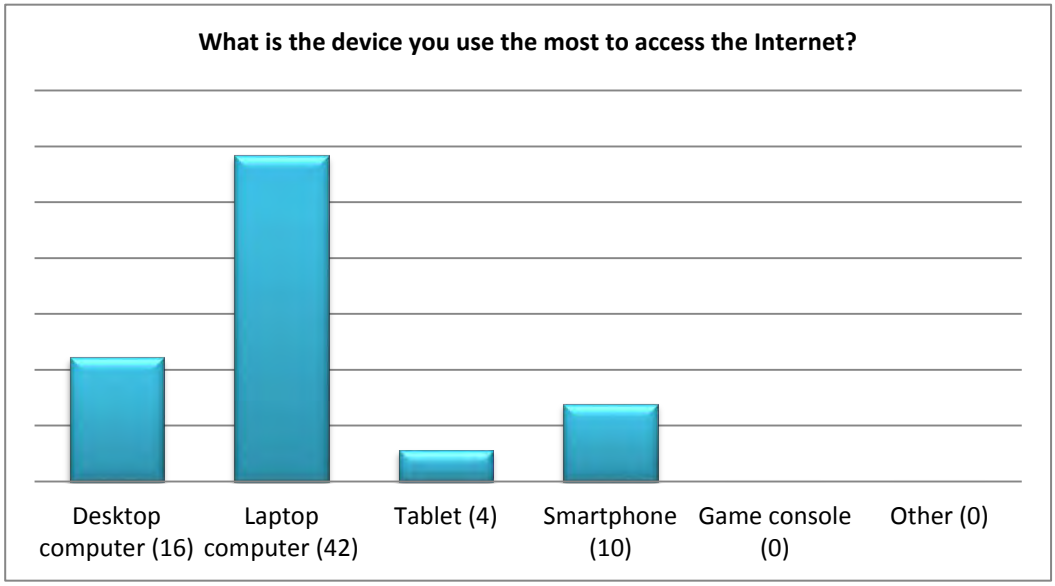


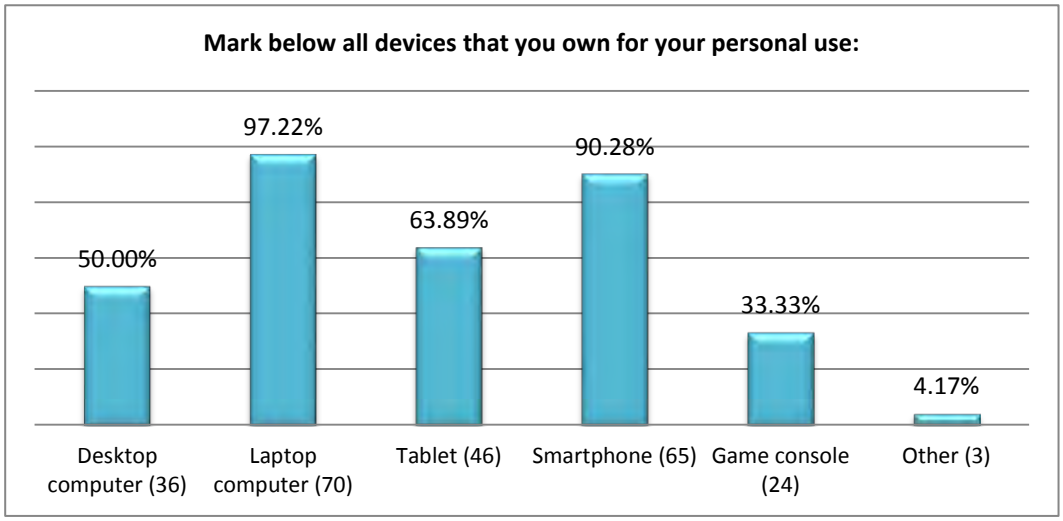


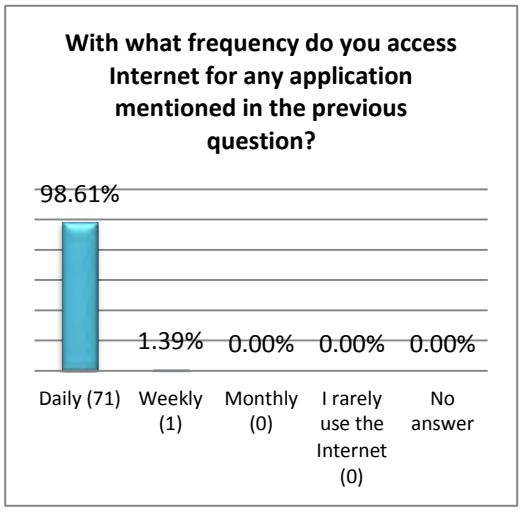


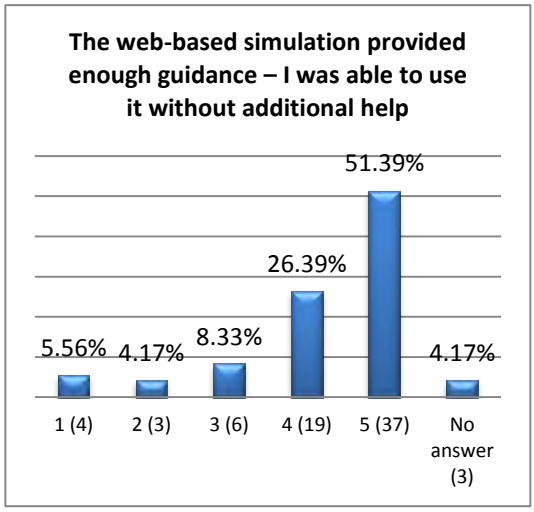
How much preparation do you typically do before starting a training session with those simulations?	
Count	28
Sum	42.75
Standard deviation	1.7
Average	1.53
Minimum	0
1st quartile (Q1)	0.625
2nd quartile (Median)	1
3rd quartile (Q3)	2
Maximum	8

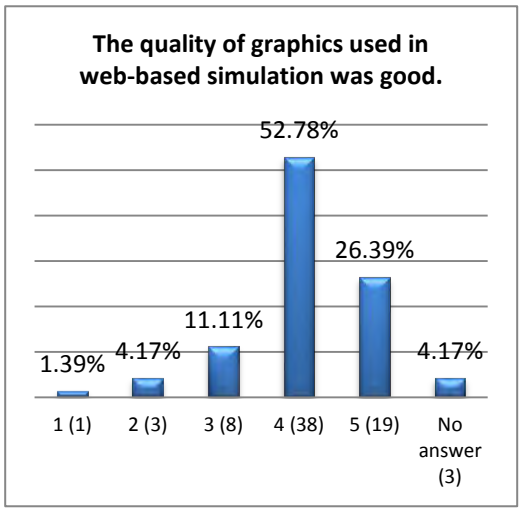


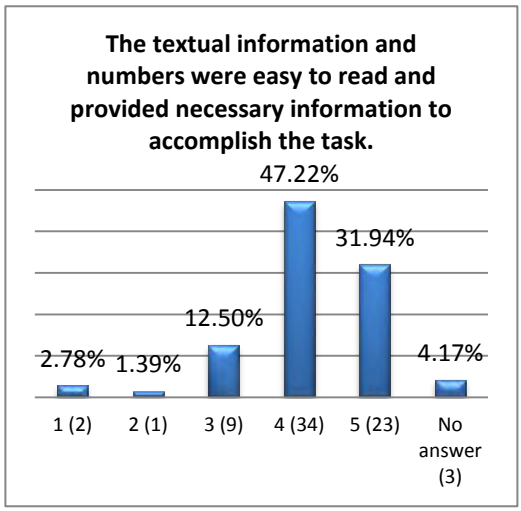

What is the device you use the most to access the Internet?
Desktop computer (16)
Laptop computer (42)
Tablet (4)
Smartphone (10)
Game console (0)
Other (0)

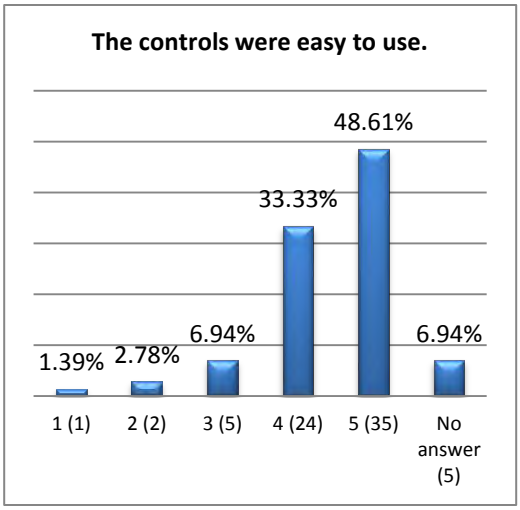

Mark below all devices that you own for your personal use:
50.00%
97.22%
63.89%
90.28%
33.33%
4.17%
Desktop computer (36)
Laptop computer (70)
Tablet (46)
Smartphone (65)
Game console (24)
Other (3)

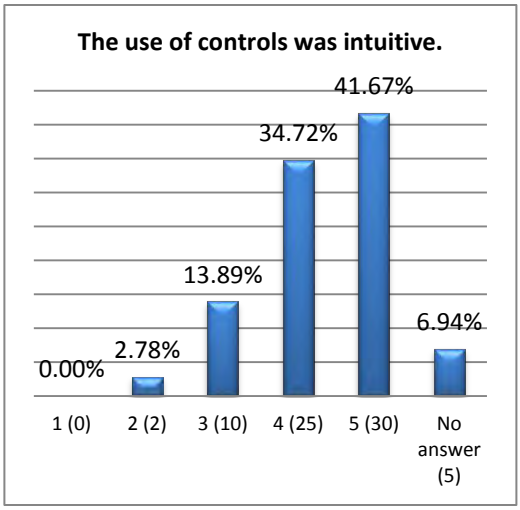

With what frequency do you access Internet for any application mentioned in the previous question?
98.61%
1.39%
0.00%
0.00%
0.00%
Daily (71)
Weekly (1)
Monthly (0)
I rarely use the Internet (0)
No answer

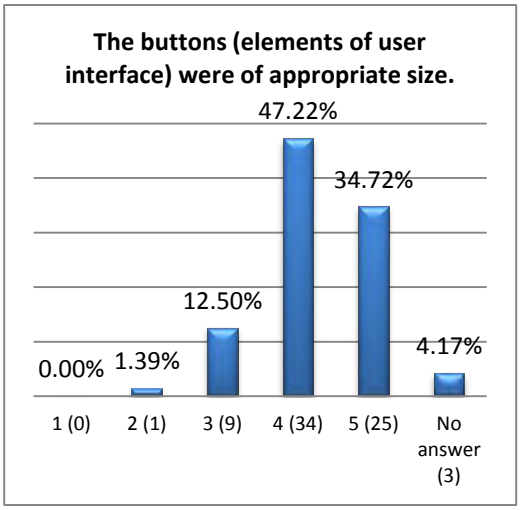

The web-based simulation provided enough guidance – I was able to use it without additional help
5.56%
4.17%
8.33%
26.39%
51.39%
4.17%
1 (4)
2 (3)
3 (6)
4 (19)
5 (37)
No answer (3)

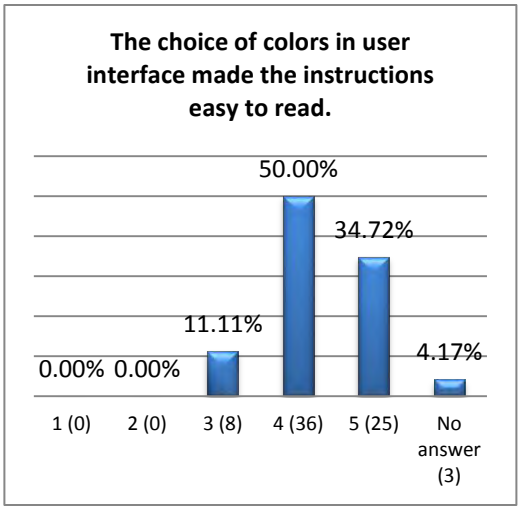

The quality of graphics used in web-based simulation was good.
1.39%
4.17%
11.11%
52.78%
26.39%
4.17%
1 (1)
2 (3)
3 (8)
4 (38)
5 (19)
No answer (3)

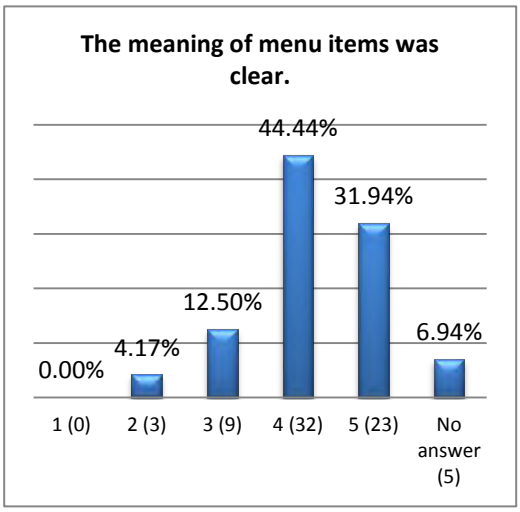

The textual information and numbers were easy to read and provided necessary information to accomplish the task.
2.78%
1.39%
12.50%
47.22%
31.94%
4.17%
1 (2)
2 (1)
3 (9)
4 (34)
5 (23)
No answer (3)

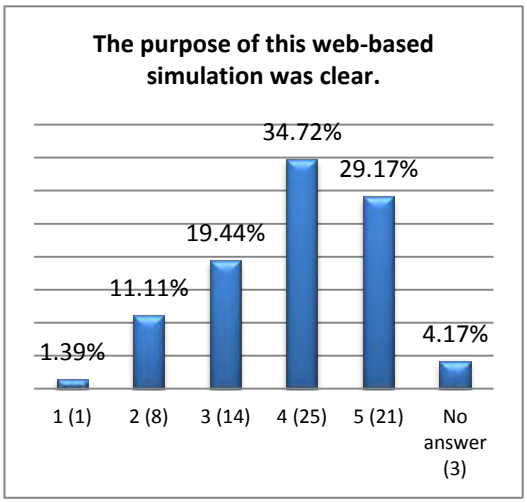

The controls were easy to use.
48.61%
33.33%
6.94%
6.94%
1.39%
2.78%
1 (1)
2 (2)
3 (5)
4 (24)
5 (35)
No answer (5)

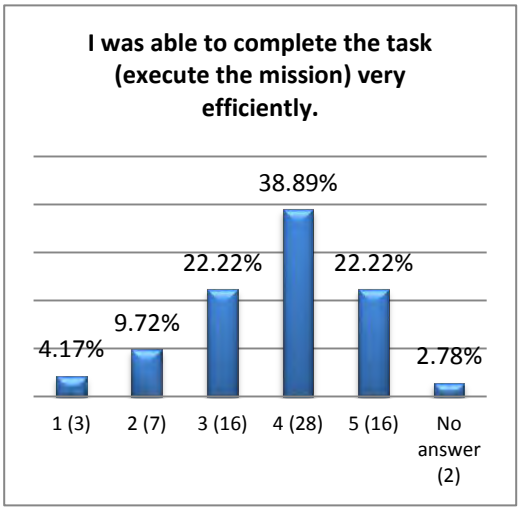

The use of controls was intuitive.
41.67%
34.72%
13.89%
6.94%
0.00%
2.78%
1 (0)
2 (2)
3 (10)
4 (25)
5 (30)
No answer (5)

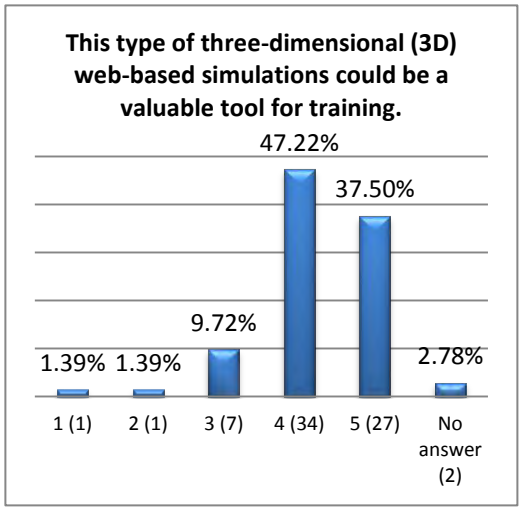

The buttons (elements of user interface) were of appropriate size.
47.22%
34.72%
12.50%
4.17%
0.00%
1.39%
1 (0)
2 (1)
3 (9)
4 (34)
5 (25)
No answer (3)

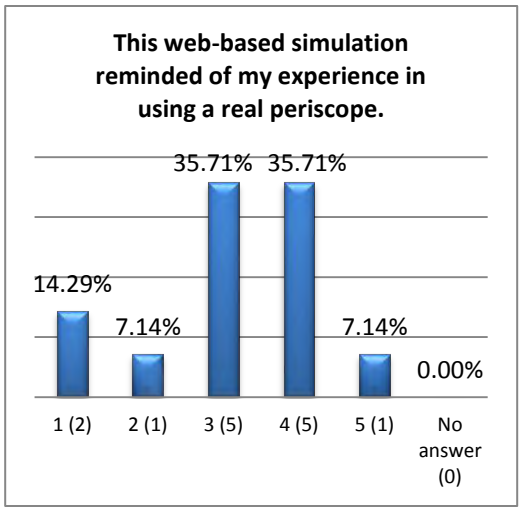

The choice of colors in user interface made the instructions easy to read.
50.00%
34.72%
11.11%
4.17%
0.00%
0.00%
1 (0)
2 (0)
3 (8)
4 (36)
5 (25)
No answer (3)

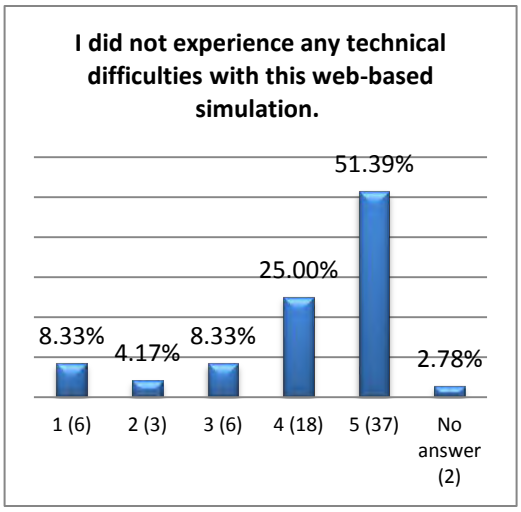

The meaning of menu items was clear.
0.00%
4.17%
12.50%
44.44%
31.94%
6.94%
1 (0)
2 (3)
3 (9)
4 (32)
5 (23)
No answer (5)

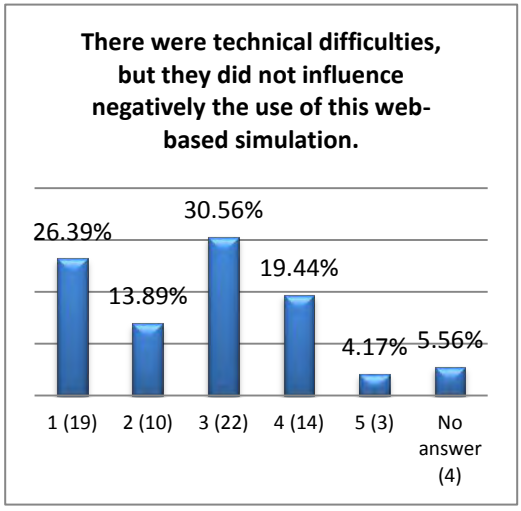

The purpose of this web-based simulation was clear.
1.39%
11.11%
19.44%
34.72%
29.17%
4.17%
1 (1)
2 (8)
3 (14)
4 (25)
5 (21)
No answer (3)

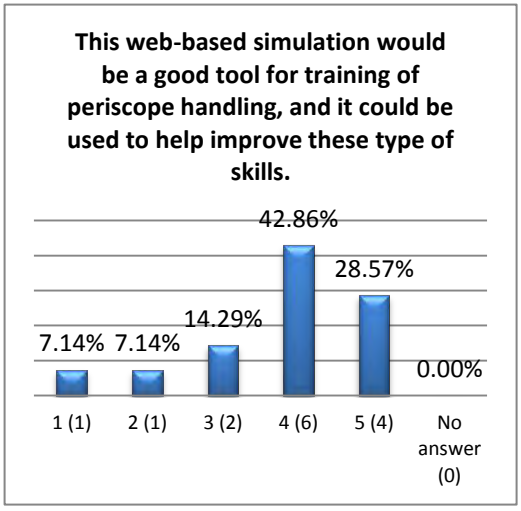

I was able to complete the task (execute the mission) very efficiently.
4.17%
9.72%
22.22%
38.89%
22.22%
2.78%
1 (3)
2 (7)
3 (16)
4 (28)
5 (16)
No answer (2)

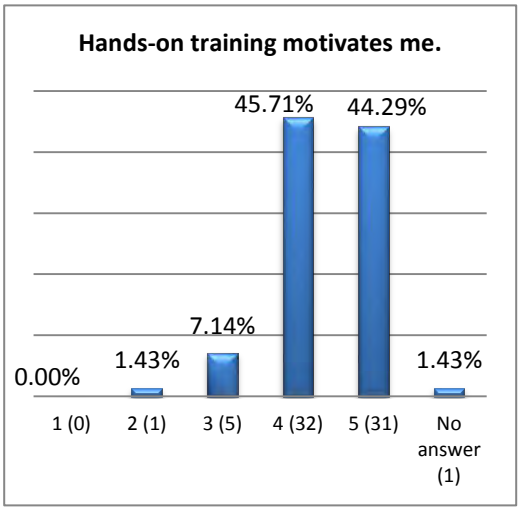

This type of three-dimensional (3D) web-based simulations could be a valuable tool for training.
1.39%
1.39%
9.72%
47.22%
37.50%
2.78%
1 (1)
2 (1)
3 (7)
4 (34)
5 (27)
No answer (2)

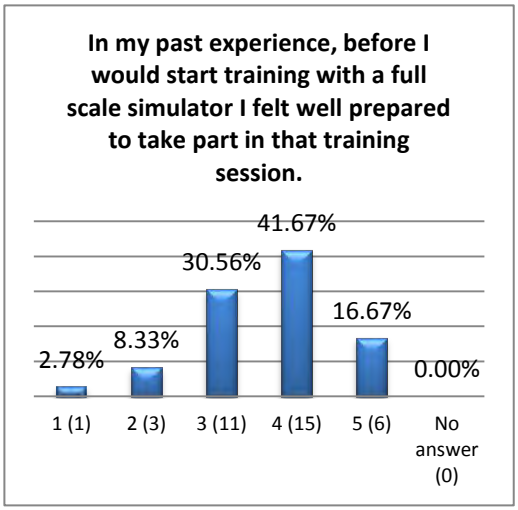

This web-based simulation reminded of my experience in using a real periscope.
14.29%
7.14%
35.71%
35.71%
7.14%
0.00%
1 (2)
2 (1)
3 (5)
4 (5)
5 (1)
No answer (0)

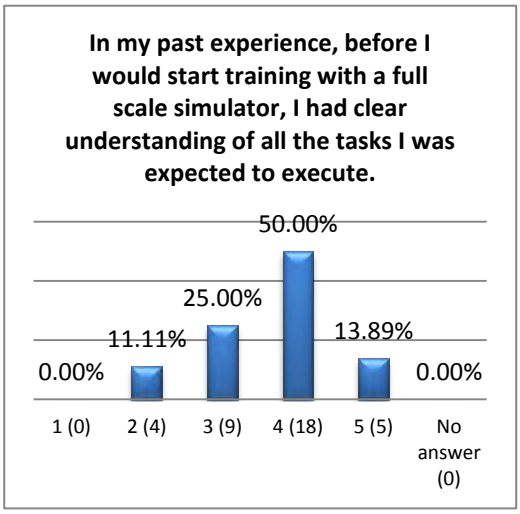

I did not experience any technical difficulties with this web-based simulation.
8.33%
4.17%
8.33%
25.00%
51.39%
2.78%
1 (6)
2 (3)
3 (6)
4 (18)
5 (37)
No answer (2)

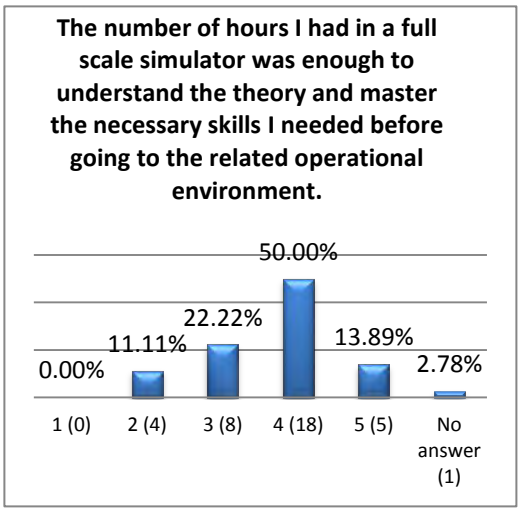

There were technical difficulties, but they did not influence negatively the use of this web-based simulation.
26.39%
13.89%
30.56%
19.44%
4.17%
5.56%
1 (19)
2 (10)
3 (22)
4 (14)
5 (3)
No answer (4)

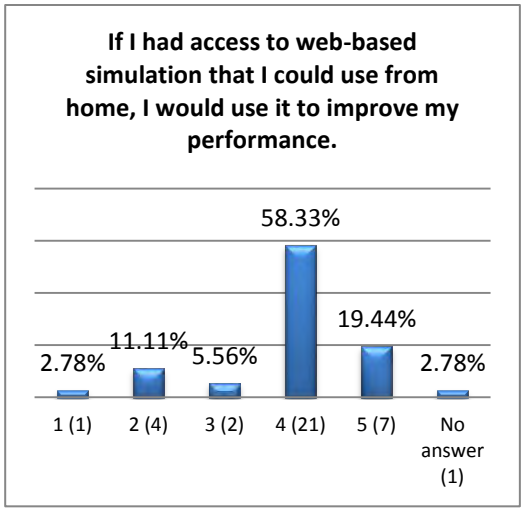

This web-based simulation would be a good tool for training of periscope handling, and it could be used to help improve these type of skills.
7.14%
7.14%
14.29%
42.86%
28.57%
0.00%
1 (1)
2 (1)
3 (2)
4 (6)
5 (4)
No answer (0)

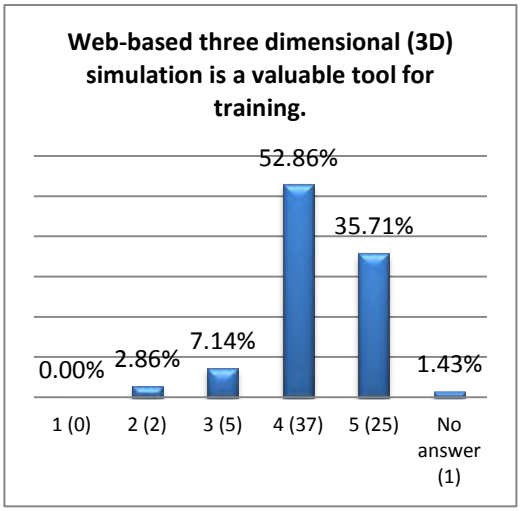

Hands-on training motivates me.
0.00%
1.43%
7.14%
45.71%
44.29%
1.43%
1 (0)
2 (1)
3 (5)
4 (32)
5 (31)
No answer (1)

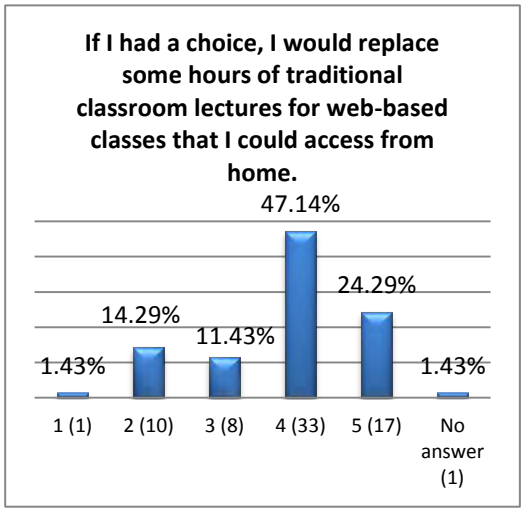

In my past experience, before I would start training with a full scale simulator I felt well prepared to take part in that training session.
2.78%
8.33%
30.56%
41.67%
16.67%
0.00%
1 (1)
2 (3)
3 (11)
4 (15)
5 (6)
No answer (0)

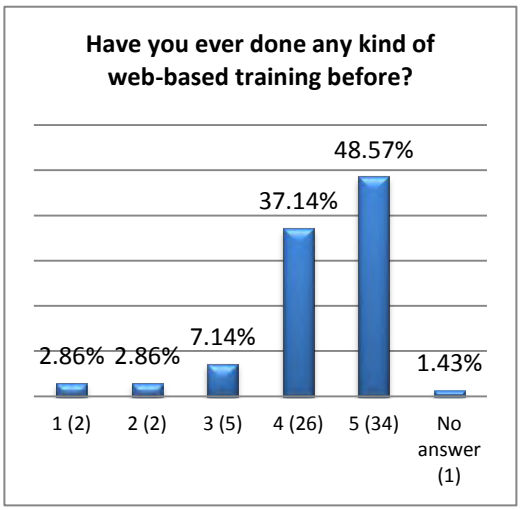

In my past experience, before I would start training with a full scale simulator, I had clear understanding of all the tasks I was expected to execute.
0.00%
11.11%
25.00%
50.00%
13.89%
0.00%
1 (0)
2 (4)
3 (9)
4 (18)
5 (5)
No answer (0)

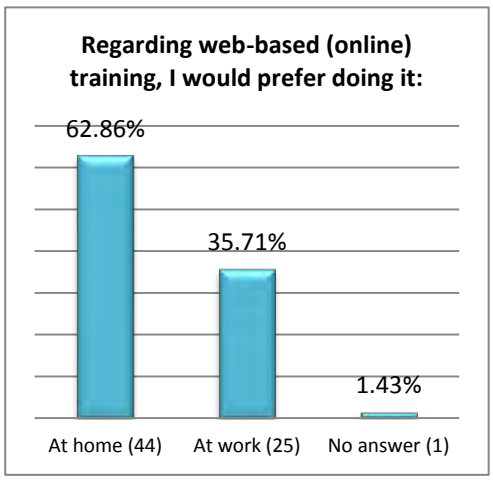

The number of hours I had in a full scale simulator was enough to understand the theory and master the necessary skills I needed before going to the related operational environment.
0.00%
11.11%
22.22%
50.00%
13.89%
2.78%
1 (0)
2 (4)
3 (8)
4 (18)
5 (5)
No answer (1)

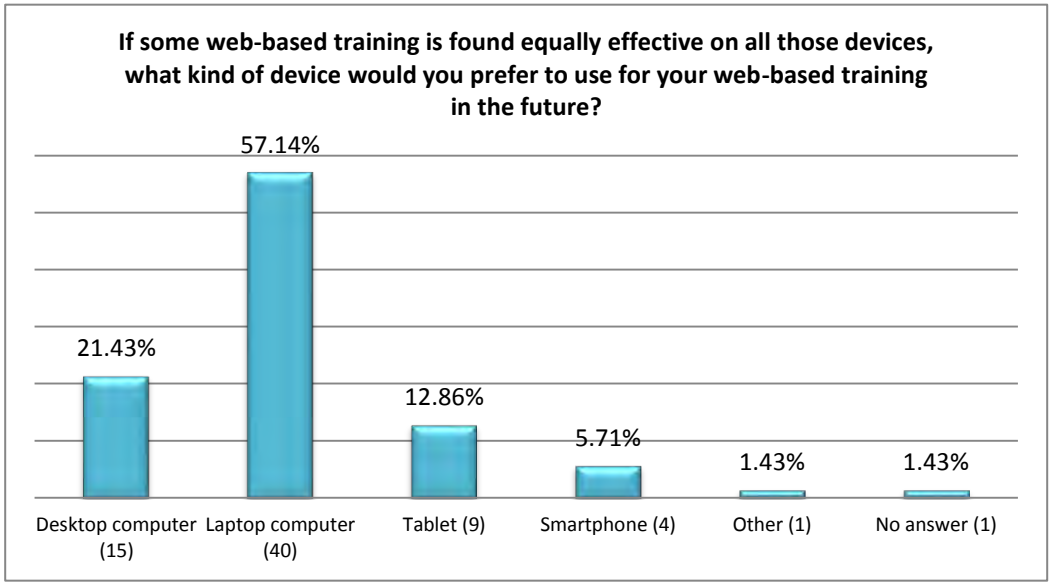

If I had access to web-based simulation that I could use from home, I would use it to improve my performance.
2.78%
11.11%
5.56%
58.33%
19.44%
2.78%
1 (1)
2 (4)
3 (2)
4 (21)
5 (7)
No answer (1)

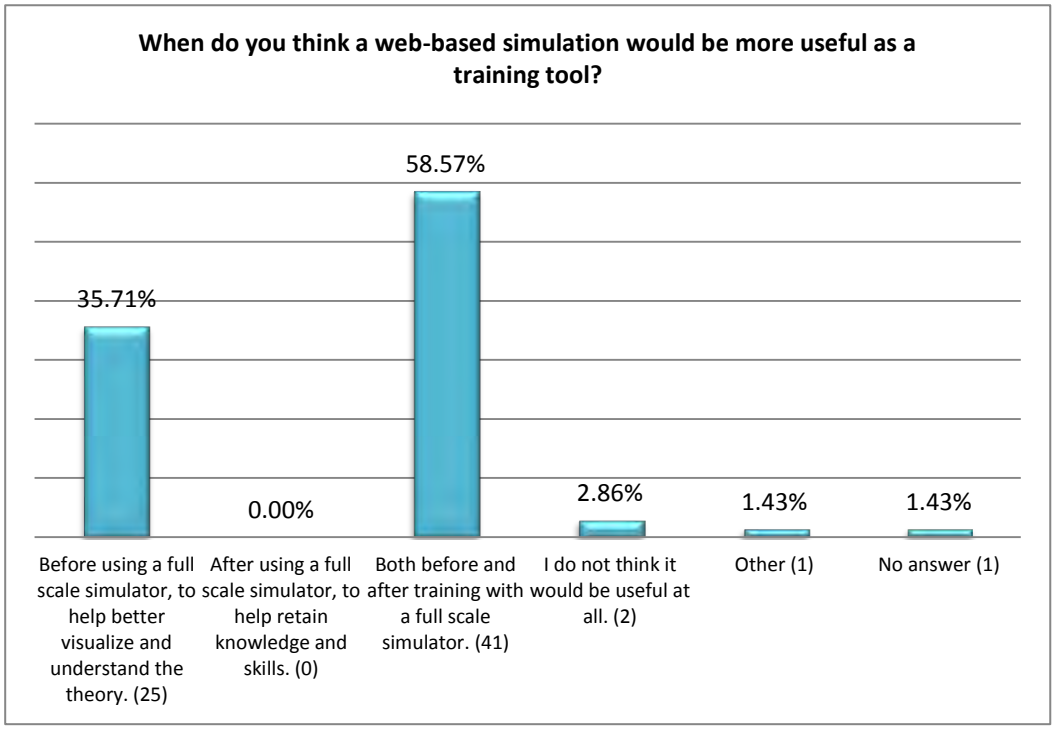

Web-based three dimensional (3D) simulation is a valuable tool for training.
0.00%
2.86%
7.14%
52.86%
35.71%
1.43%
1 (0)
2 (2)
3 (5)
4 (37)
5 (25)
No answer (1)


If I had a choice, I would replace some hours of traditional classroom lectures for web-based classes that I could access from home.
1.43%
14.29%
11.43%
47.14%
24.29%
1.43%
1 (1)
2 (10)
3 (8)
4 (33)
5 (17)
No answer (1)


Have you ever done any kind of web-based training before?
2.86%
2.86%
7.14%
37.14%
48.57%
1.43%
1 (2)
2 (2)
3 (5)
4 (26)
5 (34)
No answer (1)


Regarding web-based (online) training, I would prefer doing it:
62.86%
35.71%
1.43%
At home (44)
At work (25)
No answer (1)


If some web-based training is found equally effective on all those devices, what kind of device would you prefer to use for your web-based training in the future?
21.43%
57.14%
12.86%
5.71%
1.43%
1.43%
Desktop computer (15)
Laptop computer (40)
Tablet (9)
Smartphone (4)
Other (1)
No answer (1)


When do you think a web-based simulation would be more useful as a training tool?
35.71%
0.00%
58.57%
2.86%
1.43%
1.43%
Before using a full scale simulator, to help better visualize and understand the theory. (25)
After using a full scale simulator, to help retain knowledge and skills. (0)
Both before and after training with a full scale simulator. (41)
I do not think it would be useful at all. (2)
Other (1)
No answer (1)

LIST OF REFERENCES

Ahmad, R., Piccoli, G., & Ives, B. (1998). Effectiveness of virtual learning environments in basic skills business education: A field study in progress. In *ICIS '98 Proceedings of the International Conference on Information Systems* (pp. 352–357). Atlanta, GA, USA: Association for Information Systems.

Annett, J. (2003). Hierarchical task analysis. In Hollnagel, E. (Ed.), *Handbook of Cognitive Task Design* (pp. 17–35). Mahwah, NJ: CRC Press.

Anyuru, A. (2012). *Professional WebGL Programming: Developing 3D Graphics for the Web*. (P. Brunt, Ed.) (p. 333). West Sussex, UK: John Wiley & Sons, Ltd.

Bandura, A. (1986). *Social Foundation for Thought and Action*. Englewood Cliffs, NJ: Prentice Hall.

Becker, K., & Parker, J. R. (2009). A simulation primer. In Gibson, D. & Baek, Y. (Eds.), *Digital Simulations for Improving Education: Learning Through Artificial Teaching Environments*. Hershey, PA: IGI Global.

Berry, M. (2006). *An Investigation of the Effectiveness of Virtual Learning Environment Implementation in Primary Education*. UK: University of Leicester.

Biegel, P., Brown, S., Mason, T., & Poland, D. (1998). Development of a personal computer simulation-based multimedia ship control training program. *Johns Hopkins APL Technical Digest*, *19*(4). Retrieved from http://www.jhuapl.edu/techdigest/TD/td1904/biegel.pdf

Bloom, B. (1984). The two sigma problem: The search for methods of group instruction as effective as one-to-one tutoring. *Educational Researcher*, *13*(6), 4–16.

Bouny, J. (2014). Ocean. *GitHub*. REtrieved from https://github.com/jbouny/ocean.

Brodlie, K., El-khalili, N., & Li, Y. (2000). Using web-based computer graphics to teach surgery. *Computers & Graphics*, *24*(1), 157–161.

Brooks, F. (1994). Is there any real virtue in virtual reality? *Public Lecture Cosponsored by the Royal Academy of Academy of Engineering and the British Computer Society, London*, 1–23. Retrieved from http://www.cs.unc.edu/~brooks

Bryson, S. (1996). Virtual reality in scientific visualization. *Communications of the ACM*, *39*(5), 62–71. Retrieved from http://dl.acm.org/citation.cfm?id=229467

Buss, A. H., & Stork, K. A. (1996). Discrete-event simulation on the World Wide Web using Java. In *Proceedings of the 28th Conference on Winter Simulation* (pp. 780–785). IEEE Computer Society.

Buss, A., Page, E. H., Fishwick, P. A., Healy, K. J., Nance, R. E., & Paul, R. J. (2000). Web-based simulation: revolution or evolution? *ACM Transactions on Modeling and Computer Simulation (TOMACS)*, *10*(1), 3–17. doi:10.1145/353735.353736

Byrne, J., Heavey, C., & Byrne, P. J. (2010). A review of web-based simulation and supporting tools. *Simulation Modelling Practice and Theory*, *18*(3), 253–276. doi:10.1016/j.simpat.2009.09.013

Cannon-Bowers, J. A., Salas, E., & Grossman, J. D. (1992). Improving tactical decision making under stress. *The 27th International Applied Military Psychology Symposium: A Focus on Decision Making Research* (p. 49). Retrieved from http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA265278#page=51

Chou, S.-W., & Liu, C.-H. (2005). Learning effectiveness in a web-based virtual learning environment: A learner control perspective. *Journal of Computer Assisted Learning*, *21*(1), 65–76. doi:10.1111/j.1365-2729.2005.00114.x

Chung, C. A. (2003). *Simulation Modeling Handbook: A Practical Approach*. Retrieved from http://books.google.com/books?hl=en&lr=&id=JhV6Ry6UMDQC&oi=fnd&pg=PP2&dq=Simulation+Modeling+Handbook:+A+Practical+Approach&ots=JiTEnN_-Jg&sig=Dj_iwCAd6gWJMi1yNYi5e8lY_Fc

Clark, R. E. (1994). Media will never influence learning. *Educational Technology Research and Development*, *42*(2), 21–29. Retrieved from http://link.springer.com/article/10.1007/BF02299088

Compeau, D. R., & Higgins, C. A. (1995). Computer self-efficacy: Development of a measure and initial test. *MIS Quarterly*, *19*(2).

Cook, D. A. (2007). Web-based learning: Pros, cons and controversies. *Clinical Medicine*, *7*(1), 37–42.

Cook, D. A., Garside, S., Levinson, A. J., Dupras, D. M., & Montori, V. M. (2010). What do we mean by web-based learning? A systematic review of the variability of interventions. *Medical Education*, *44*(8), 765–774.

Crandall, B., Klein, G., & Hoffman, R. R. (2006). *Working Minds: A Practitioner's Guide to Cognitive Task Analysis*. Cambridge, MA: Massachusetts Institute of Technology.

Cui, X., Yicheng, J., Xiuwen, L., & Yong, Y. (2004). Web-based maritime training environment. *The Fourth International Conference on Computer and Information Technology, 2004. CIT '04*, 351–356. doi:10.1109/CIT.2004.1357220

Deveria, A. (2014). Can I use... Support tables for HTML5, CSS3, etc. *Feature: WebGL - 3D Canvas Graphics*. Retrieved from http://caniuse.com/#feat=webgl

Ehret, B. D., Benjamin, M., Gray, W. D., & Kirschenbaum, S. S. (1997). *Subgoaling and Subschemas for Submariners: Cognitive Models of Situation Assessment*. Newport, RI: Naval Undersea Warfare Center Division.

Endsley, M. R. (1995). Toward a theory of situation awareness in dynamic systems. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *37*(1), 32–64. doi:10.1518/001872095779049543

Entin, E. E., & Serfaty, D. (1990). *Information Gathering and Decision-Making Under Stress* (Vol. 4901). Burlington, MA. Alphatech, Inc.

Fischer, S. C., Spiker, V. A., & Riedel, S. L. (2009). *Critical Thinking Training for Army Officers, Volume III: Development and Assessment of a Web-based Training Program*. Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

Fishwick, P. (1996). Web-based simulation: Some personal observations. In *Proceedings of the 28th Conference on Winter Simulation*. IEEE Computer Society. Retrieved from http://dl.acm.org/citation.cfm?id=256807

Flanagan, D. (2011). *JavaScript: The definitive guide* (6th ed.). Cambridge, MA: O'Reilly Media, Inc.

Forster, M. (1996). Training for stressful environments: Implications for the Royal Navy. *Contemporary Ergonomics*, 240–245.

Garris, R., & Ahlers, R. (2001). A game-based training model: Development, application, and evaluation. In *The Interservice/Industry Training, Simulation & Education Conference (I/ITSEC)*. Retrieved from http://ntsa.metapress.com/link.asp?id=jfqueeaxn93nbkjm

Gellman, G. W. (2005). *Using web-based interactive multimedia to supplement traditional teaching methods: A pilot program for medical training of non-medical personnel*. (Master's thesis, Naval Postgraduate School). ADA432230.pdf. Retrieved from http://oai.dtic.mil/oai

Gopher, D., Well, M., & Bareket, T. (1994). Transfer of skill from a computer game trainer to flight. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *36*(3), 387–405. doi:10.1177/001872089403600301

Hara, N., & Kling, R. (2000). Students' distress with a web-based distance education course: An ethnographic study of participants' experiences. *Information, Communication and Society*, *3*(4), 557–579.

Harasim, L., Calvert, T., & Groeneboer, C. (1997). Virtual-U: A web-based system to support collaborative learning. In B. H. Khan (Ed.), *Web-Based Instruction* (pp. 149–158). Englewood Cliffs, NJ: Educational Technology Publications, Inc.

Hills, H. (2003). *Individual Preferences in e-Learning*. England: Gower Publishing Limited.

Hoffman, R. R., Crandall, B., & Shadbolt, N. (1998). Use of the critical decision method to elicit expert knowledge: A case study in the methodology of cognitive task analysis. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *40*(2), 254–276. doi:10.1518/001872098779480442

Huang, Y., & Madey, G. (2005). Autonomic web-based simulation. In *Proceedings of the 38th Annual Symposium on Simulation*. IEEE Computer Society. Retrieved from http://dl.acm.org/citation.cfm?id=1050748

Hutchins, S. (1996). *Principles for Intelligent Decision Aiding*. Retrieved from http://link.springer.com/chapter/10.1007/978-1-4613-1447-9_8

Jones, M. (2008). Simulation across the spectrum of submarine training. In *Proceedings of the 2008 Spring Simulation Multiconference* (pp. 811–815). San Diego, CA: Society for Computer Simulation International.

Khronos Group. (2011). WebGL - OpenGL ES 2.0 for the Web. Retrieved from http://www.khronos.org/webgl/

Khronos Group. (2014). Blacklists and whitelists: WebGL public wiki. Retrieved from http://www.khronos.org/webgl/wiki/BlacklistsAndWhitelists

Kindley, R. (2002). The power of simulation-based e-learning (SIMBEL). *The E-Learning Developers' Journal*, 1–8. Retrieved from http://library.ilsworld.com/papers/pdfs/Kindley-Sept-17-2002.pdf

Kirlik, A., Fisk, A. D., Walker, N., & Rothrock, L. (1998). Feedback augmentation and part-task practice in training dynamic decision-making skills. In *Making Decisions under Stress: Implications for Individual and Team Training* (pp. 91–113). Retrieved from 10.1037/10278-004\nhttp://ezproxy.net.ucf.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=psyh&AN=1998-06532-004&site=ehost-live

Kirschenbaum, S. S. (1989). *Information Gathering for Adaptable Decision-Making*. Arlington, VA. Retrieved from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA206488

Kirschenbaum, S. S. (2001). Analyzing submarine decision making: A question of levels. In E. Salas & G. Klein (Eds.), *Linking Expertise and Naturalistic Decision Making* (pp. 189–207). Mahwah, NJ: Psychology Press.

Kirschenbaum, S. S., Trafton, J. G., Schunn, C. D., & Trickett, S. B. (2013). Visualizing uncertainty: The impact on performance. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *56*(3), 509–520. doi:10.1177/0018720813498093

Klein, G. (1993). *A Recognition-primed Decision (RPD) Model of Rapid Decision Making*. Ablex Publishing Corporation. Retrieved from http://www.ise.ncsu.edu/nsf_itr/794B/papers/Klein_1989_AMMSR_RPDM.pdf

Klein, G. (1996). The effect of acute stressors on decision making. In J. E. Driskell & E. Salas (Eds.) *Stress and Human Performance* (pp. 49–88). Mahwah, NJ: Lawrence Erlbaum Associates.

Klein, G. (2008). Naturalistic decision making. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *50*(3), 456–460. doi:10.1518/001872008X288385

Klein, G. A., Calderwood, R., & MacGregor, D. (1989). Critical decision method for eliciting knowledge. *Systems, Man and Cybernetics, IEEE Transactions on*, *19*(3), 462–472. Retrieved from http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=31053

Kuljis, J., & Paul, R. J. (2000). A review of web-based simulation: Whither we wander? In *Proceedings of the 32nd conference on Winter simulation,* vol. 2, (pp. 1872–1881). Society for Computer Simulation International. doi:10.1109/WSC.2000.899181

Landsberg, C. R., Mercado, A. D., Van Buskirk, W. L., Lineberry, M., & Steinhauser, N. (2012). Evaluation of an adaptive training system for submarine periscope operations. *Proceedings of the Human Factors and Ergonomics Society annual meeting*, *56*(1), 2422–2426. doi:10.1177/1071181312561493

Lepper, M. R. (1985). Microcomputers in education: Motivational and social issues. *American Psychologist*, *40*(1), 1–18.

Maki, R. H., Maki, W. S., Patterson, M., & Whittaker, P. D. (2000). Evaluation of a web-based introductory psychology course: Learning and satisfaction in on-line versus lecture courses. *Behavior Research Methods, Instruments, & Computers*, *32*(2), 230–239. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/10875167

McKenna, I. H., & Little, S. (2000). Developing tactics using low cost, accessible simulations. In *Proceedings o f the 2000 Winter simulation conference,* vol. 1, (pp. 991–1000). IEEE. Retrieved from http://www.informs-sim.org/wsc00papaers/130.pdf

Milheim, W. D., & Martin, B. L. (1991). Theoretical bases for the use of learner control: Three different perspectives. *Journal of Computer Based Instruction*. Retrieved from http://psycnet.apa.org/psycinfo/1992-04146-001

Moraes, C. C. (2011). *Design and task analysis for a game-based shiphandling simulator using an open source game engine (Delta3D)*. (Master's thesis, Naval Postgraduate School). Retrieved from http://edpcs.nps.edu/npspubs/scholarly/theses/2011/September/11Sep_de_moraes.pdf

Nair, R., Miller, J. A., & Zhang, Z. (1996). A Java-based query driven simulation environment. In *Proceedings of the 28th conference on Winter simulation* (pp. 786–793). IEEE Xplore. doi:10.1109/WSC.1996.873366

NATO. (2002). *MXP-1 (D)(NAVY)(AIR) Multi-national Submarine and Anti-submarine Exercise Manual, Vol. 1*. Standardization Agency of the North Atlantic Treaty Organization.

Orlansky, J., Dahlman, C., Hammon, C., Metzko, J., Taylor, H. L., & Youngblut, C. (1994). *The value of simulation for training (No. IDA-P-2982)*. Alexandria, VA. Retrieved from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA289174

Piccoli, G., Ahmad, R., & Ives, B. (2001). Web-based virtual learning environments: A research framework and a preliminary assessment of effectiveness in basic IT skills training. *MIS Quarterly*, *25*(4), 401–426. Retrieved from http://www.jstor.org/stable/3250989

Psotka, J., Massey, L. D., & Mutter, S. A. (1988). *Intelligent Tutoring Systems: Lessons Learned*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Reeves, T. C. (1993). Pseudoscience in computer-based instruction: The case of learner control research. *Journal of Computer-Based Instruction*, *20*(2), 39–46.

Reeves, T. C., & Reeves, P. M. (1997). Effective dimensions of interactive learning on the World Wide Web. In B. H. Khan (Ed.), *Web-Based Instruction* (pp. 59–66). Englewood Cliffs, NJ: Educational Technology Publications, Inc.

Reijerse, R. (2006). Roel z'n Boel - Free skyboxes. Retrieved from http://reije081.home.xs4all.nl/skyboxes/

Ritchie, D. C., & Hoffman, B. (1997). Incorporating instructional design principles with the World Wide Web. In B. H. Khan (Ed.), *Web-Based Instruction* (pp. 135–138). Englewood Cliffs, NJ: Educational Technology Publications, Inc.

Salas, E., Bowers, C., & Rhodenizer, L. (1998). It is not how much you have but how you use it : Toward a rational use of simulation to support aviation training. *The International Journal of Aviation Psychology*, *8*(3), 197–208. doi:10.1207/s15327108ijap0803

Salas, E., & Burke, C. S. (2002). Simulation for training is effective when ... *Quality and Safety in Health Care*, *11*(2), 119–120. doi:10.1136/qhc.11.2.119

Salas, E., & Cannon-Bowers, J. A. (2001). The science of training: A decade of progress. *Annual Review of Psychology*, *52*(1), 471–499.

Schmitz, C. (2012). LimeSurvey Project Team. *LimeSurvey: An open source survey tool*. Hamburg, Germany: LimeSurvey Project. Accessed August 30, 2014. Retrieved from http://www.limesurvey.org

Shattuck, L. G., & Miller, N. L. (2004). A process tracing approach to the investigation of situated cognition. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *48*(3), 658–662. doi:10.1177/154193120404800382

Shattuck, L. G., & Miller, N. L. (2006). Extending naturalistic decision making to complex organizations: A dynamic model of situated cognition. *Organization Studies*, *27*(7). Retrieved from http://www.dtic.mil/dtic/tr/fulltext/u2/a487772.pdf

Simon, S. J., & Werner, J. M. (1996). Computer training through behavior modeling, self-paced, and instructional approaches: A field experiment. *Journal of Applied Psychology*, *81*(6), 648–659. doi:10.1037//0021-9010.81.6.648

Sitzmann, T. (2011). A meta-analytic examination of the instructional effectiveness of computer-based simulation games. *Personnel Psychology*, *64*(2), 489–528. doi:10.1111/j.1744-6570.2011.01190.x

Sitzmann, T., Kraiger, K., Stewart, D., & Wisher, R. (2006). The comparative effectiveness of web-based and classroom instruction: A meta-analysis. *Personnel Psychology*, *59*(3), 623–664. doi:10.1111/j.1744-6570.2006.00049.x

Stanney, K. M., Kennedy, R. S., & Drexler, J. M. (1997). Cybersickness is not simulator sickness. In *Proceedings of the Human Factors and Ergonomics Society annual meeting* (pp. 1138–1142). SAGE Publications.

Stanton, N. A. (2006). Hierarchical task analysis: Developments, applications and extensions. *Applied Ergonomics*, *37*(1), 55–79.

Steketee, M. (2004). Perisher sets the pass mark for submarine command. *Jane's Navy International*, *109*(10), 20–25.

Stone, R. J. (2002). Applications of virtual environments: An overview. In *Handbook of virtual environments: Design, implementation, and applications*. Retrieved from http://psycnet.apa.org/psycinfo/2002-00153-042

Taipjutorus, W., Hansen, S., & Brown, M. (2012). Improving learners' self-efficacy in a learner-controlled online learning environment: A correlational study. *ASCILITE-Australian Society for Computers in Learning in Tertiary Education annual conference*, *2012*(1). Retrieved from http://www.ascilite2012.org/images/custom/taipjutorus,_widchaporn_-_improving.pdf

Thompson, T. N., Carroll, M. B., & Deaton, J. E. (2009). Justification for use of simulation. In *Human Factors in Simulation* (pp. 39–48). Retrieved from http://books.google.com/books?hl=en&lr=&id=cgT56UW6aPUC&oi=fnd&pg=PA39&dq=Justification+for+Use+of+Simulation&ots=8ivO_0XmcE&sig=dERTQl8_hHv6X4Ak7aSwsKh7-ME

U.S. Department of Defense, (1994). D.5000.59-M: *Glossary of Modeling and Simulation Terms*. Washington, DC: U.S. DOD.

VanLehn, K. (2011). The relative effectiveness of human tutoring, intelligent tutoring systems, and other tutoring systems. *Educational Psychologist*, *46*(4), 197–221. doi:10.1080/00461520.2011.611369

Vincenzi, D. A., Hays, R. T., & Seamon, A. G. (2003). Submarine officer of the deck training using virtual environments: An assessment of training system capabilities. *Naval Engineers Journal*, *115*(1), 79–95. doi:10.1111/j.1559-3584.2003.tb00189.x

White, D. S. H. (1993). The submarine command course. In *The Naval Review* (Vol. 81, pp. 362–365). London, UK: Naval Society.

Wightman, D., & Lintern, G. (1985). Part-task training for tracking and manual control. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *27*(3), 267–283. doi:10.1177/001872088502700304

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